

Lightweight Tennis Ball Pick Up & Hopper Final Design Review

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Team

Pursuit of Hoppiness

By

Tyler Noxon
tnoxon@calpoly.edu

George DeGrandis
gdegrand@calpoly.edu

Alejandro Morales
amoral26@calpoly.edu

Sponsor

Professor John Chen

Project Advisor

Professor Peter J. Schuster

Mechanical Engineering Department

California Polytechnic State University

San Luis Obispo

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Abstract

Within this document, the “Pursuit of Hoppiness” team will clarify some of the details associated with completing this design project. The project is focused on designing a mechanism for tennis players and coaches of all ages that is able to collect tennis balls around a tennis court, specifically around the net and fence. The goal is to make the final product lightweight, inexpensive, and easy to use. With multiple ideation sessions, the team was able to brainstorm several ideas that serve the above functions and constraints.

The initial process began with choosing two different ideas that followed through until the beginning of the final phase of our senior project timeframe. The two prototypes were built to show the functions of gathering and collecting tennis balls. At this point, both prototypes were presented to our sponsor so that as a team, one prototype was chosen to move forward with. The Paddlewheel mechanism was chosen as the final product to build and deliver.

There were multiple tests performed on the Paddlewheel mechanism to ensure the intended goals were met. This project includes a functionality of a four-bar linkage system that incorporates a locking component that locks the linkage system and bin at different positions. For the second iteration of this project, there will be a cable-locking system implemented on the handle that will allow the user to pull a smaller handle that will disengage the locking pin for ease of rotating the four-bar linkage system.

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1 Introduction

Professor John Chen at Cal Poly introduced the problem of designing a lightweight tennis ball pick-up and hopper. Although other solutions currently exist to solve this problem, they are either too expensive, too hard to use, or too bulky. Some research on the alternative solutions can be found in the Background Section. Some of the more general goals of this project are discussed below. First, team members want to design a product that solves all the needs of our customers. This includes both our sponsor, Dr. Chen, as well as other tennis players of varying ages. Once this goal is met, team members can also focus on secondary goals like designing a good-looking, innovative design that would make customers focus on the elegance of the product even when it does such a simple task.

The background section will demonstrate the research that has been done towards a solution. This includes notes on an interview with the sponsor, some customer research into existing designs, a patent search, and some technical research pertaining to the subject. Next, in the Objectives section, the scope of the problem will be assessed. This will include various techniques including a defined problem statement, a boundary diagram, and a QFD table. The concept design development section shows our decision process and its final results. This will include the concept selection process, as well as some preliminary analyses on the chosen designs. At the end of this section, the two prototyped ideas will be described in depth. After this section is the Final Design section, where the final prototypes of both the belt drive and the paddlewheel mechanisms are described in depth. This section will also describe the selection process where our two final prototypes were narrowed down to one final design. The Manufacturing section will discuss all of the manufacturing techniques used to construct both final prototypes. Next, the Design Verification section will describe and list the results of the five tests ran on the prototype of our final design. In the Project Management section, the overall design process of the project will be investigated. This will include showing some of the key deliverables using a Gantt chart, and some of the special techniques that will be used to solve the problem. Finally, the conclusion will summarize the document and propose some future changes to the mechanism.

2 Background

The research done by the team was focused on the customer wants and needs. The team created a survey with specific questions that were tailored to our problem definition. This survey aided the direction on what functions and aspects were most important in our design. The research also includes existing patents and technical information that is in more detail below.

2.1 Interview with Sponsor

To better understand the scope of the project, a meeting was conducted with our sponsor and potential customer, Professor Chen. Currently, Professor Chen owns a Wilson Tennis Ball Hopper as seen in Figure A.1. The current problems he has encountered with it are that the welds are beginning to break apart after less than two years of use, the hopper itself is too heavy for his 5-year old son to use, and the hopper is not comfortable to carry around. Professor Chen has

emphasized the need for a better mechanism for tennis players to use with ease that is low-cost, durable, and with no electronic devices.

2.2 Tennis Club Survey

To obtain additional information on the importance of different design criteria, a survey was sent to the Cal Poly Tennis Club. The survey received 17 responses from club members and the results were implemented into the Quality Function Deployment Document. The survey questions and general responses can be seen in Appendix A. From conducting this survey, the most important design criteria to the players were mobility, durability, and ease of use. The least important criteria were it being comfortable, adjustable, and inexpensive. The average number of balls that the players wanted to carry was about 75 balls. In the comments from the questionnaire about issues with current designs, most players indicated that they break easily, are heavy, flimsy, and hard to transport. In the comments regarding things that the players wished they had, the players indicated that they wanted it lightweight, able to store tennis balls, able to change from a hopper to a stand, and more stable.

2.3 Existing Designs and Patent Research

As a part of the background research, existing products were examined and rated on a scale from 1 (poor) to 5 (great) in terms of their performance in each of the categories listed in Table 1. The categories of Table 1 were generated based off our sponsor list of wants, as well as other aspects that the team deemed important. The benchmarking of these products allowed us to determine what methods of tennis ball collecting were the most effective and allowed the team to understand who the main competitors are. From the products we benchmarked, the Kollektaball CS60 (item 4) and Tomohopper (item 8) stood out the most due to the overall unweighted score, as well as the technologies employed. The Kollektaball CS60 converts into a ball holder after collection and has small metal wires that allow the tennis balls to roll into the main cavity during collection. The Tomohopper is a rolling ball collector that allows for ball collecting along the fence and net due to its arm shape. It picks up the balls in grooves in the wheels and deposits them into a main collector bin. After collecting the tennis balls, the bin can be mounted higher up to serve as a ball stand. Photos of these products can be seen in Appendix A.

Table 1. Benchmarking of current products.

	Wilson Tennis Hopper	Har-Tru Ball Mower	Roller Mower	Kollect- aball	Multi- mower	Rapid Ball Boy	Hill Hopper	Tomo- hopper	Brad Tennis Ball Retriever
Carry Enough Tennis Balls	5	5	5	4	5	5	5	5	5
Light Weight	5	1	4	4	2	1	1	3	3
Durable	1	4	1	2	5	2	5	5	5
Mobile (to and from the car)	5	1	3	5	3	2	1	4	3
Inexpensive	5	2	4	4	3	1	1	3	4
Easy to use	2	4	3	3	4	5	1	4	3
Comfortable	1	2	2	3	1	2	1	4	3
Purely Mechanical	5	5	5	5	5	5	5	5	5
Adjustable	1	1	4	4	1	1	1	1	1

While conducting background research, a patent search was done to see what kinds of solutions had been patented. During this research, five separate patented ideas were examined to learn about the competition as well as find some promising attributes that could be included in the final design. Since this is a problem with a wide variety of solutions, many patents exist that would solve the problem. However, the four patents chosen represented very different and innovative ways of solving the problem. A table of the four patents examined can be seen in Table 2.

Table 2. Patent search related to tennis ball hoppers.

Patent Name	Patent Number	Key Characteristics
Tennis Ball Retrieving Storage Container	US 4412697 A	<ul style="list-style-type: none"> • Similar wire frame as common solution • Handles adapt to form stand, acts as lifted storage
Tennis Ball Retriever and Storage Cart	US 5301991 A	<ul style="list-style-type: none"> • Rolling unit, pushed with horizontal bar • Hopper is in between two wheels • Picks up balls with curved wireframe
Tennis Ball Retrieval Cart and Practice Hopper	US 7341294 B2	<ul style="list-style-type: none"> • Rolling unit, pushed with horizontal bar • Has arms to guide balls before pick-up • Balls picked up by wheel spokes
Tennis Ball Collection, Dispensing, and Transport Apparatus	US 20060068948 A1	<ul style="list-style-type: none"> • Rolling unit, pushed with single diagonal bar (adjustable) • Uses paddlewheel motion to pick-up

This patent search was conducted using Google Patent Search. In the case of the first two patents on the table, these were issued over 20 years ago and since have expired. As a result, all manufacturers are now able to manufacture and sell these products. The next patent on the list is

still active today and poses a unique solution to our problem. In this patent design, arms and slots guide the tennis balls into the spokes of the wheels used to drive the mechanism. Then, as the wheels spin, the balls are lifted into a bin. In the fourth and final patent of Table 2, a paddlewheel like one of our designs picks up balls and spits them into a basket. However, this patent was abandoned, and thus the idea is still available for production today. This abandonment could have been a result of an inability to reply to the patent office within a given time period, or through a formal expression of abandonment by the applicant. [1] Regardless of the reason for abandonment, this idea is still available for production today. Similarly, there are other situations in which spherical objects need to be lifted from the ground. For example, there is a product called “Bag Shag” that can lift golf balls from the ground. It is a product that is simply a tube that has a bag attached. The user utilizes this product by pushing down on any golf ball with the tube and the golf balls are pushed upwards until the bag attached is full.

It is important to recognize that while there are many solutions to the problem we are looking to solve, not all of them have progressed to the patent stage. With this in mind, the team will look to create as many different design iterations as possible while still early in the design phase. This will result in lots of prototyping and testing, providing the team with ample amounts of applicable data about the product. Once as much data as possible is collected, then the best solution can be chosen from the different prototypes and that solution may be able to advance to the patent stage.

2.4 Technical Information

In order to learn more about tennis balls, some research was conducted to be sure that we are not adding any additional problems to the functionality of the tennis ball. According to the leading authority in the tennis world, the International Tennis Federation (ITF), tennis balls must be within an approved range of diameter. This range is 2.57-2.70 in. [2] In addition to having a regulated diameter, tennis balls also have a regulated outer surface of felt-covered rubber. This rough surface is used to trip the boundary layer in order to reduce the drag on the ball during flight. [3]

Another aspect of the tennis ball research was determining why some storage containers for tennis balls are pressurized. Since the inside of a tennis ball is pressurized to approximately twice atmospheric pressure to preserve its bouncy quality, as soon as the ball is exposed to the atmosphere, it begins to move towards pressure equilibrium and depressurize as it degrades. As a result, some storage containers are pressurized in order to reduce the leakage from the ball and allow them to last longer.

The lifetime of the tennis ball can pose some relatively unforeseen consequences due to the number of balls made per year (~325 million), and the fact that these balls are composed of not easily biodegradable rubber. [4] With this information in mind, the Pursuit of Hoppiness team has considered using a pressurized storage container to hold the balls for the tennis hopper. With the use of this pressurized container, the product would not only perform the task of picking up tennis balls, but it would also be able to increase the life of the balls by preventing leakage and maintaining the balls’ bounciness.

3 Objectives

To fully understand the overall design, the team created a boundary diagram as well as a Quality Function Deployment (QFD) plan. The QFD is shown in Appendix B.

3.1 Problem Statement

Tennis players and coaches of all ages need a way of picking up tennis balls on the court, specifically around the net and the fence. This solution will double as a holder and will transport the balls to and from the court. The mechanism will be easy-to-use, lightweight, and inexpensive by employing a novel mechanical means.

3.2 Boundary Diagram

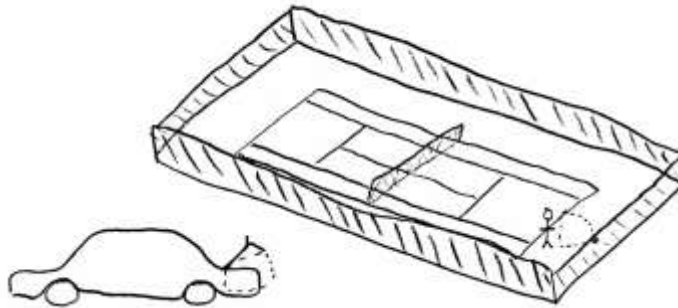


Figure 1. Boundary Diagram for tennis ball hopper.

To further understand the scope of this project, a Boundary Diagram was also created and is seen in Figure 1. The Boundary Diagram explains where the boundaries of the product are, and what outside references will play key roles in the development of the design. As seen in Figure 1, the external references that will play a part in our design decisions are the tennis court, the vehicle trunk, the player, and of course the tennis balls. The court plays a part because the design will have to maneuver within its bounds while performing and will have to interface with the net and fence. The car trunk will help define the size restrictions on our design so that we can be sure that it will be easily mobile in a variety of different vehicles. Also, the person plays a part because this product will be designed to be human powered and we will need to design according to the power output of people of all ages and sizes.

3.3 Quality Function Deployment (QFD)

The Quality Function Deployment process determined what specifications were needed for the new tennis hopper. Initially, research was done on existing products so that the needs and wants of the customers can be weighted. The team then created a list of targets that our product should achieve and weighted those targets to existing products. The specifications were then determined by the customer requirements. Parameters that reflected the customers' needs such as the hopper being lightweight, durable and inexpensive, were taken into consideration. Each specification was rated in terms of importance from 1-5 (i.e. 1-not important 5-extremely important). A full list of

the customer wants and needs is included in Appendix A. The House of Quality was developed after the QFD process and is included in Appendix B.

Table 3 is a specifications table that includes descriptions of parameters for the tennis ball hopper. A specification includes the requirements or targets that the overall design needs to meet. For example, the overall design is to be inexpensive so our goal is to design a mechanism within the range of \$100-\$200 USD.

Table 3. Specifications table for the tennis ball hopper.

Spec.#	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Carry Enough Tennis Balls	48 balls	+50/-12	L	A, T
2	Light Weight	6-10 lbs	+10-15 lbs	H	I
3	Mobile	Fit in small trunk	N/A	M	A, I, T
4	Inexpensive	\$100-\$200	+\$200/-50	H	A
5	Easy-To-Use	Pass/Fail	N/A	M	A, I, T, S
6	Comfortable	N/A	N/A	M	A, T
7	Durable	5 years	N/A	L	S
8	Purely Mechanical	Pass/Fail	N/A	M	A, I, T
9	Adjustable	5% F to 95% M	N/A	L	A, T

Table 3 is a specifications table that includes a compliance column. The methods included are Analysis (A), Test (T), Similarity to Existing Designs (S), and Inspection (I). Each compliance method was determined based on the parameter descriptions. For the testing and analysis, our group will need a prototype to check whether it meet those specifications. The risk specifications were assigned with High (H), Medium (M), and Low (L) risk factors. The following describes each specification and its importance:

- 1) Specification 1 is important when designing our product because the mechanism needs to be able to hold a certain number of tennis balls so that the use is efficient for the customers. This will be measured in terms of length, width, and height because our overall goal is to have a container that will collect the tennis balls.
- 2) The light weight description is important because the team wants the final product to be operated by customers of all ages. This specification was assigned as a high risk because the requirement or target for the product is set to be a limited weight.
- 3) Mobility is a key specification because it allows the customer to use a mechanism that can be easily maneuvered to and from the court.
- 4) To satisfy all customers, we want to make sure that the overall product is inexpensive. This will be achieved by the type of selected material for all hardware and main body of the mechanism.
- 5) As for any other product, customers want mechanisms to be easy-to-use. This is important because it will allow all customers of all ages to use something that is universal.
- 6) A comfortable mechanism in terms of usage and storage is important because it allows the users to not hassle and struggle with a product that is intended to be used with ease.
- 7) Durability is also a critical specification because we want customers to get a product that is worth the purchase. We are aiming for a target of at least five years, and since our time

frame for this project does not allow us to test that, we can estimate the lifespan of other products that will potentially use the same materials and parts.

- 8) Having a purely mechanical system is one of the main goals of this project. It is important because this specification falls into the category of customer wants.
- 9) Adjustability will allow users of different heights to use the mechanism with ease. The constraint of different heights will be removed by adding a system that will adjust to said user.

These specifications were determined from a survey that was sent out to a tennis team and other tennis players. In addition, in order to create the most appealing product for the customer, the cost was also deemed to be a high-risk specification. To deal with the high-risk specifications throughout the design, the team will consider simplicity of design as the top priority. With fewer and less complicated parts, the solution will not only be cheaper to manufacture, but also lighter.

4 Concept Design Development

The design process began with us conducting a function decomposition of our mechanism so that we could identify the three primary functions of the device. From this, we determined that our three main functions were gathering, lifting, and transporting the tennis balls. With these functions in mind, we conducted several ideation sessions to generate ideas for each function. Once the team had several ideas for multiple functions, a few conceptual models were built to get some feedback on how these ideas would function on an actual prototype. Pugh matrices were then developed by each team member for the three critical functions which were then combined in a morphological matrix to develop complete system concepts. These concepts were then put into a weighted decision matrix, scored based on how they related to our design criteria, and then the highest scoring concepts were turned into concept prototypes.

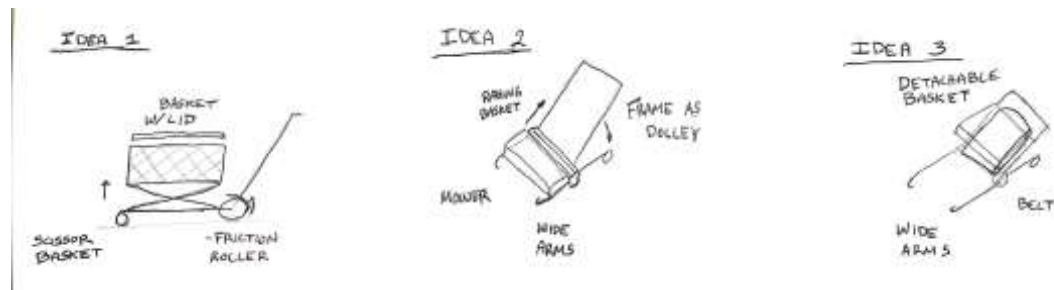
4.1 Concept Development Process and Results

Several ideation sessions were conducted that focused on the major and secondary functions as well as an overall mechanism. The first ideation session consisted of brainstorming ideas that would include any possible way that can make such a mechanism functional. Such ideas include: use of Velcro belt to scoop up tennis balls, a vacuum suction mechanism, half-circular wire frame, and spinning wheels to raise the tennis balls. The second ideation session was focused on one specific function: storing tennis balls. The ideas from this session include: a slotted box that allows the tennis balls to enter from the side, storing tennis balls in basket that can raise to waist height, and storing tennis balls in a bag that is connected to the mechanism. Ideation session number three consisted of ideas for the function of raising tennis balls. Some ideas from this session include: a scissor-like basket that can raise to a desired height by connected linkages, wedged wheels that have slots for the tennis balls that raise as the mechanism is pushed, and a crank wheel that is raised manually by the user. The last ideation session focused on the function of transporting tennis balls to and from the court. During this session, we wanted to focus on how we can create a product that was able to fit in a car and be comfortable to transport to and from the court.

4.2 Concept Selection Process

To narrow down our list of ideas to a select few possible concepts, we began by evaluating our ideas based on their feasibility. After this initial feasibility check, we then moved on to the

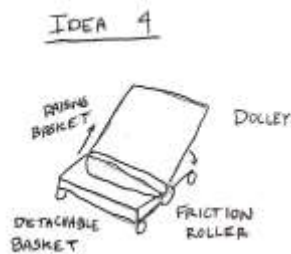
development of Pugh Matrices for each of our three main functions: transport to and from the tennis court, gathering the tennis balls, and lifting the tennis balls to a comfortable height. The Pugh Matrices compare different concepts to a single datum and can either be given a +, -, or S (same) with regards to how they compare to the chosen datum design. For these three different matrices, we used the Tomohopper as the datum, which can be seen in Appendix A. Once we determined which concepts from each function's Pugh Matrices were the best options, we then combined these stronger concepts in a morphological matrix to create full designs that satisfy the customers' requirements. We decided on five full designs from the morphological matrix and used a weighted decision matrix to determine which design would be the highest weighted so that we can move forward and begin prototyping. These five designs can be seen in Figure 2.



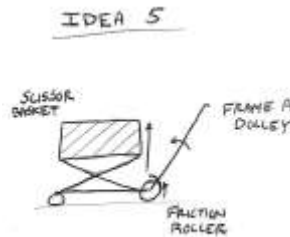
(a) Idea one showing the three combined functions of transporting, gathering, and lifting.

(b) Idea two is our paddlewheel mechanism that shows all the critical functions.

(c) Idea three is our belt drive mechanism and is the highest weighted in the decision matrix.



(d) Idea four showing four combined functions using the morphological matrix.



(e) Idea five is our potential third prototype and shows three functions from our ideations sessions.

Figure 2. The top five ideas shown as sketches. The paddlewheel mechanism (idea two) and the belt drive mechanism (idea three) were chosen to prototype with idea five as a possible third prototype.

Since our project is straightforward and not heavily dependent on analysis, we decided that building two or three prototypes would be possible. From the decision matrix, there were three other designs that were equally weighed. We decided to build the belt drive mechanism, which was our highest weighted design, and the paddlewheel mechanism. The third possible prototype we will build will be a scissor-like basket that will raise by connected linkages. The Pugh Matrices, the morphological matrix, and the weighted decision matrix are shown in Appendix C.

4.3 Concept Models and Prototypes

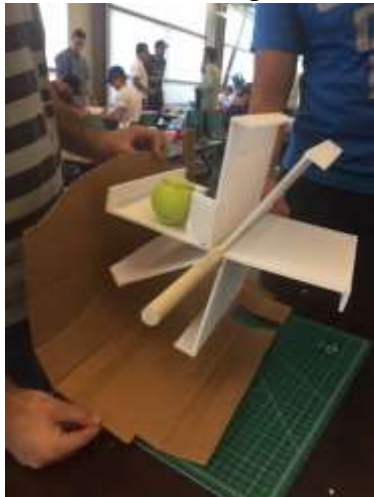
After our ideation session, we chose a few different ideas that we thought would benefit by building concept models. These models were designed to simply illustrate some of the key functions without the need for heavy manufacturing. During our concept model build day, we were able to take a look at four separate ideas that covered the functions of lifting and gathering.



(a) Belt-roller Concept – Lifting.



(b) Friction Roller Concept – Gathering.



(c) Paddlewheel Concept – Gathering.



(d) Ball Lifter Tube – Lifting.

Figure 3. Concept model build results.

Figure 3 depicts the outcomes of our concept model build day. From these four concept models, we were able to rule out some ideas and understand what difficulties may be found ahead. One of the ideas that we were able to rule out from building the concept models was the Ball Lifter Tube Idea because we found that lifting the tennis balls with a bottom sliding plate was more difficult than we had thought. We also learned from these models that if we went with a belt drive mechanism, we would need to have the rollers perfectly aligned to keep the belt from sliding off of the rollers.

After building our concept models and completing the matrices discussed above, we narrowed down our options and moved on to develop conceptual prototypes to get a first look at how some of these concepts might function on a large scale. For our concept prototypes, we focused on two major functions for gathering and lifting: the paddlewheel mechanism and the belt drive mechanism. These two functions were key components to our overall design concepts that scored the highest on our weighted matrix. Figure 4 depicts the concept prototypes that we built for the testing of these functions.



(a) Paddlewheel mechanism concept prototype.



(b) Belt drive mechanism concept prototype.

Figure 4. Concept prototype build results.

Although these concept prototypes were not fully functioning mechanisms, they provided us with valuable information that is crucial to the concepts moving forward. For the paddlewheel mechanism, we realized that the roller will more than likely must be larger so that the balls can make it into our basket. Also, we found that this design can sometimes get caught up on tennis balls if it does not encounter them at the right location. For the belt drive mechanism, we observed that as the belt loses tension, it becomes ineffective at lifting the tennis balls. This is a major problem that would need to be corrected with an adequate belt or belt tensioner to keep the belt taught. We also learned that with the wheels directly driving the belt, it takes a long time for the balls to get from the ground to the top of the channel. This is a problem that we can solve by separating the belt rollers from the wheels and adding gearing to allow the belt to rotate faster.

4.4 Preliminary Analyses

Some preliminary analyses were conducted in order to highlight some additional design challenges for our final design. By looking at some of the loads that will act on our designed mechanism, we had the opportunity to see additional features that might be needed for the design to be feasible. Hand calculations for this analysis can be seen in Appendix D. Also, some of the analyses focused on certain things we need to watch out for to increase the life of the product.

4.4.1 Wind force

An analysis of the drag forces due to wind was conducted on our chosen concepts. Since the belt drive mechanism has the largest surface area exposed to wind, this design would be exposed to the largest wind loads. After an analysis of the drag on our belt drive mechanism, it was determined that the maximum wind load that this device would experience under a 60-mph wind would be 41.5 lb. Not only would this wind force oppose the force used to push the mechanism, but it would also cause the belt drive to be pushed all over the court even when the user wanted it stationary. Since a wind load this large would present significant problems, some steps must be taken in our design to alleviate this problem. First of all, our team intends to include wheel locks that will lock the mechanism in place to prevent unwanted movement. Additionally, a smaller belt could be used in order to lower the wind force, or a belt that allows air to pass through it.

4.4.2 Force required to lift tennis ball

According to the ITF, the acceptable mass of a tennis ball is a range of 56.0-59.4 grams.ⁱ With this parameter in mind, the total weight of 72 tennis balls is around 10 pounds. This chosen tennis ball number comes from the fact that a large case of balls contains 72 tennis balls. Estimating the weight of the basket to be around 5 pounds, the total lifting force required to lift a full basket of balls will be around 15 pounds.

4.4.3 Basket Sizing

Another calculation was done in order to find the minimum possible size for our basket. In order to fit our maximum carrying capacity of 72 tennis balls, a basket or bin with a volume of at least 0.322 ft³ must be used. However, in order to account for vibrations or the bounciness of the tennis balls, a safety factor will be applied to this volume in order to find the volume for our final basket.

4.4.4 Weather Resistance

An additional analysis was conducted to determine what effects the weather could have on the life of our design. Because the tennis ball hopper will be used throughout the year, it will need to be able to function in all types of weather conditions, including heavy exposure to moisture and temperature changes. We initially examined different materials that we could use for structural parts to be sure that corrosion was kept to a minimum to promote longevity of the device. Some materials that we are considering are stainless steel, aluminum alloys, carbon steel, and some plastics such as UV stabilized HDPE (high density polyethylene). The advantage of using the stainless steel is that it has a high percentage of chromium that creates a protective barrier against corrosion. Additionally, aluminum has a similar mechanism in the formation of aluminum oxide which protects the metal from the outside environment and will happen naturally, or through the anodizing process. If we decided to use plain carbon steel, we will have to be sure that the metal is covered in a protective paint or coating that will keep the iron from oxidizing and forming rust.

on the product. If we decide to go the route that uses HDPE for structure rather than metal, we can decrease weight and still maintain high weather resistance. If we do decide to use a metal, we will need to make sure that there is no induced galvanic corrosion due to moisture, at least two dissimilar metals, and direct metal to metal contact. Some ways to circumvent this is to use rubber or nylon washers to separate the two materials when fastening, also, if the surface area difference between the two metals is great, then the effect of galvanic corrosion will be negligible. [5]

4.5 Detailed Description of Selected Concepts

There are our two main concepts that were selected and built as prototypes. Our first chosen concept is the paddlewheel mechanism and our second chosen concept is the belt drive mechanism. These two main concepts are the ideas that we thought had the most potential to fulfill the needs of our customers.

4.5.1 Belt Drive Mechanism



Figure 5. Belt Drive Mechanism Concept.

The belt drive mechanism, shown in Figure 5, utilizes a large belt to transport the balls up a surface to a desired height for ease of handling while playing tennis. The belt is driven from the rotation of the wheels so that as the device operates by rolling around the court, and the lifting of tennis balls occurs simultaneously. The purpose of this design is so that the user does not need to lift the basket of tennis balls from a lower position to a desired height which negates the issue of the basket being too heavy to carry. The back surface will have a curved surface over the top of the belt that will direct the tennis balls into the basket mounted on the front. The overall size and dimensions of this concept are similar to our first concept, and rough dimensions can be found in Appendix E.

This concept will also utilize wide arms to assist in efficient gathering of the tennis balls. To make the mechanism more transportable, the collection box will be detachable, the rear castor wheels will fold up, and the wide arms will either detach, or fold up as well. The wheels can be seen folded up in Figure 6 where the mechanism can be pulled like a dolly or suitcase from the vehicle to the court.

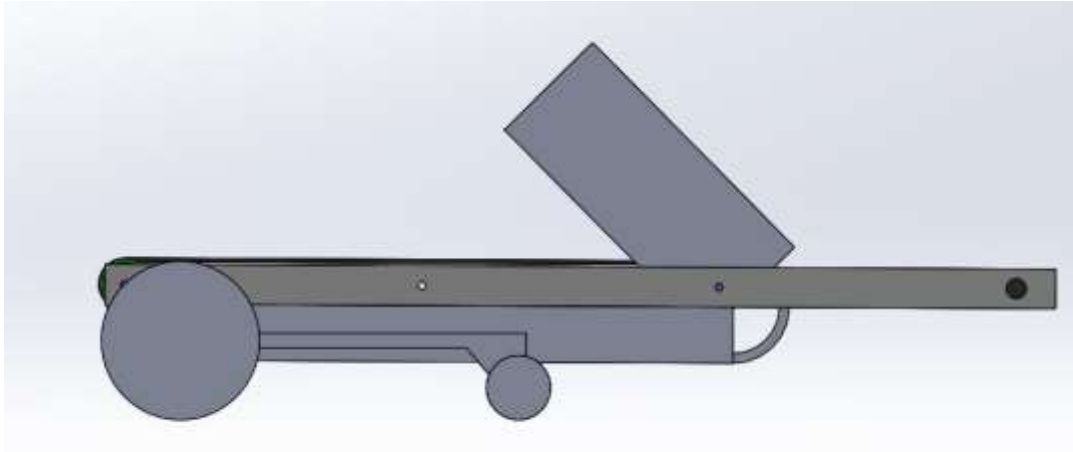


Figure 6. Rear wheels folded up for easy transport.

The project will meet our design goals by serving the proposed functions of lifting, gathering, and transporting. Also, this mechanism would require no additional changes to convert from lifting to gathering because of the combination of these functions with the belt. The materials used, total cost, and manufacturing process will be determined at a later stage in the design process. We determined through our initial prototype that this mechanism could benefit from removing the belt rollers from the direct drive of the wheels. This could increase the velocity of the belt by changing the ratio between the drive wheels and the belt roller. Main components for this design are identified in Figure 7.

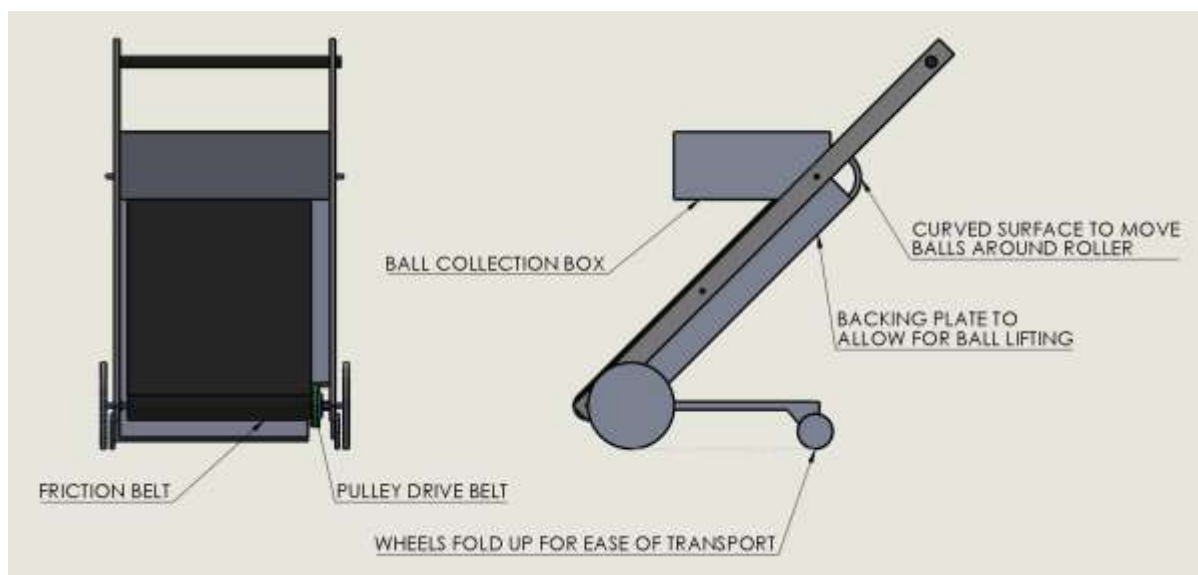


Figure 7. Belt drive mechanism at the first stages of design.

There are a few hazards or risks that come with both chosen concepts that need to be addressed. First, the mechanisms both have rolling and revolving actions. The plan for the belt and the paddlewheel is to cover them both with either a plastic casing or thin sheet metal. Since the belt and paddlewheel will be revolving, there are potential risks in pinch points which will be addressed with the casing on both systems. Second, the mechanisms are designed to carry tennis balls in a basket at certain heights, so the potential of tipping is possible. To correct this possible problem, analysis on tipping and wind loads will be determined and incorporated in the final products. Additional calculations on tipping and wind loads can be found in Appendix D. An additional risk for the belt drive mechanism is the tension in the belt. If the belt becomes too slack, it will not be able to lift the balls effectively, and they may fall back down to the ground. For the belt drive mechanism, one current unknown is the method for transferring the tennis balls from the ground to the belt to be lifted. In our concept prototype, we were not able to test this out but it will be one of our next tests to be sure that this is feasible.

4.5.2 Paddlewheel Mechanism



Figure 8. Paddlewheel Mechanism Concept.

The paddlewheel mechanism shown in Figure 8 will use a paddlewheel or friction roller that rolls and scoops up tennis balls as the user pushes the device forward. The mechanism will be approximately 40" in height and will include wide arms that will have an approximate spread of 40" for efficient gathering around the tennis courts, including the edges and net. Rough dimensions for this concept can be found in Appendix E. We will also include a basket that will be approximately 14"x19"x6" so that it is able to meet our desired capacity of 72 tennis balls. The basket will be attached in front of the paddlewheel with enough clearance for tennis balls to pass below it, into the paddlewheel. The basket will slide on rails to varying heights to account for players of all ages. The change from collector to stand can be seen in Figure 9, which documents one of the possible basket heights.

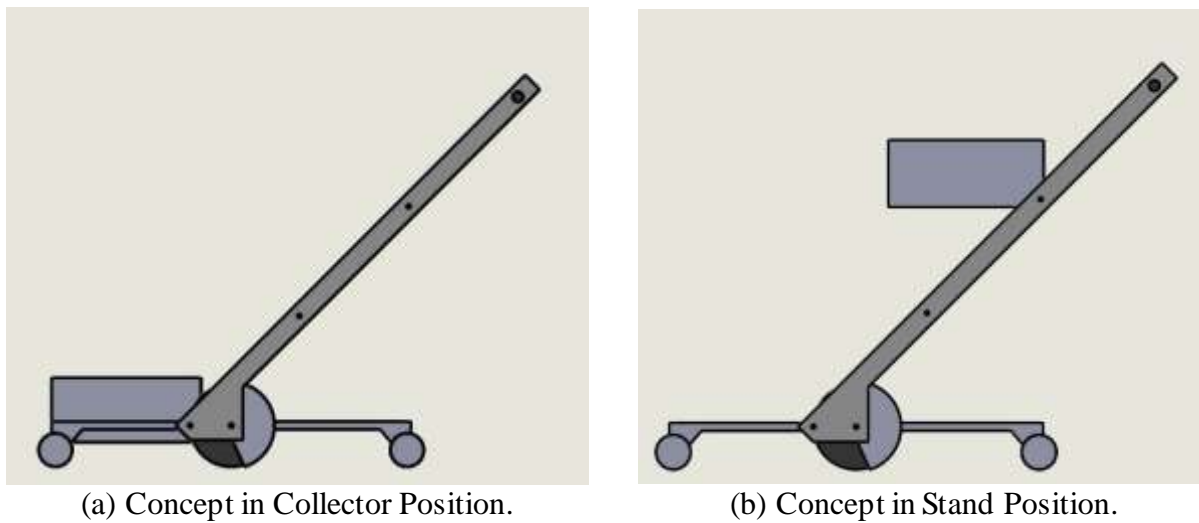


Figure 9. Paddlewheel Mechanism in two main positions.

For the paddlewheel to pick up tennis balls, a backing plate is required to keep the balls in the slots while rotating. The paddlewheel backing plate will most likely be made from a semi-flexible plastic or thin sheet metal and can be seen in Figures 9a and 9b. This design will also implement castor wheels so that the mechanism will be able to maneuver the court with ease. For ease of transport, the basket will be removable and the castor wheels will fold up so the mechanism can have a smaller footprint in the vehicle, and so it will be easy to roll to the court.

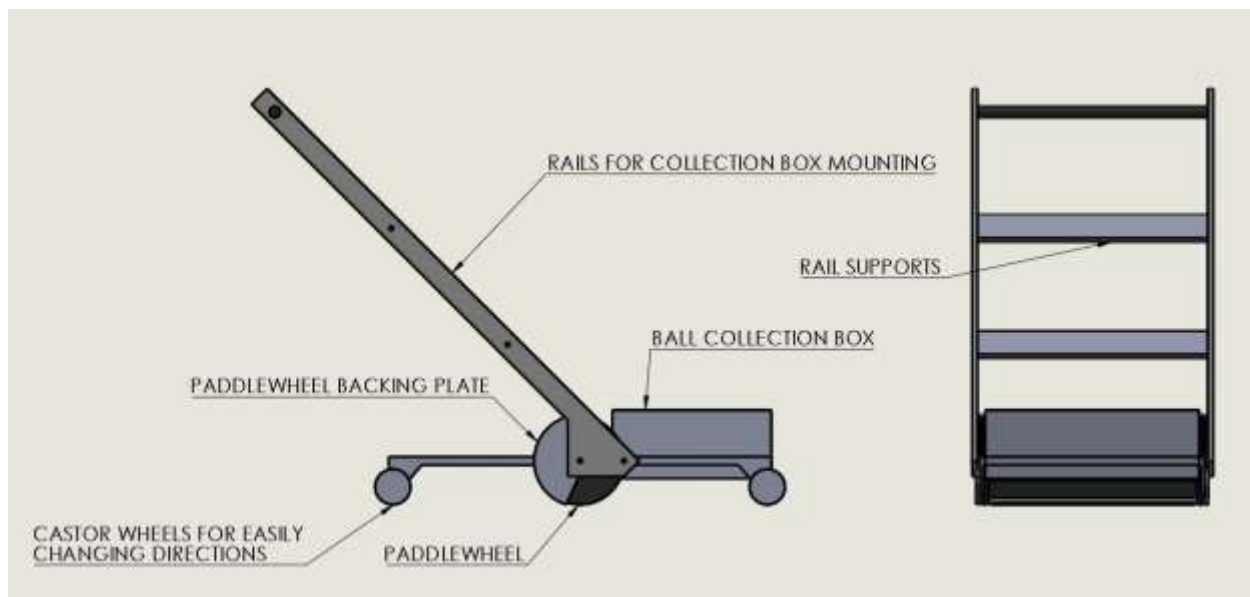


Figure 10. Paddlewheel mechanism at the first stages of design.

This concept will be able to meet our project goals because it will be easy to use, lightweight and simple. It will meet our ball capacity and hopefully it will be within our designated price range. This design considers our three main functions and provides flexibility in basket height. The cost

and materials will be determined during our second stage of building a structural prototype. This concept is straight forward, however, there is some risk associated with the basket lifting and getting the balls into the basket. The current design has the basket slide on rails to different heights, but we are also considering ways to automate this process. Through automation, the customer will not have to lift the basket to the desired height. This is a current unknown that we will continue to research to find an elegant solution. The other risk we have is getting the balls all the way into the basket. Because the tennis balls need to pass underneath the collection box, the box sits higher and is more difficult to get balls into. We are testing ways to solve this issue by incorporating a ball buffer that will overflow into the collection box.

4.5.3 Preliminary Plans for Construction

Our preliminary plans for construction are to first find materials and processes that will be the same or similar to what is used on our actual concept prototype. Additionally, we will continue to search for components that do not need to be manufactured to keep our total costs down. Once we determine what materials will be chosen to proceed with our design, we will build a structural prototype and begin the testing phase. As mentioned above, we plan on testing a minimum of two designs including the belt drive mechanism and the paddlewheel mechanism.

5 Final Design

The selection of a final design for this project was slightly different from other senior projects. The Prototype Decision section will talk about exactly why the decision was made to choose the final design from our two concepts. However, since this decision came after the critical design review, this chapter will contain the description of both the belt drive and the paddlewheel mechanisms.

5.1 Prototype Decision

After completing the manufacturing for both prototypes, we were able to narrow down our project direction after consulting with our sponsor, Dr. Chen, with our thoughts of the prototypes. We ultimately decided to go with the paddlewheel mechanism over the belt drive mechanism. After doing some preliminary testing with both prototypes, we found that the drive belt for the belt was beginning to slip and not transfer energy efficiently. This was a major issue as it would halt the rotation of the belt, stopping the mechanism from functioning correctly. In addition to this, we found the belt drive mechanism harder to maneuver and more difficult to modify into a more compact solution. With this decision made, we began to modify the paddle mechanism to address issues that we encountered during our first build. As a result of this decision, this chapter will define the functionality of both prototypes, but the description of the paddlewheel mechanism will go into much more depth.

5.2 Belt Drive Mechanism

The Belt Drive Mechanism was our first prototype that will be discussed briefly in this section. Furthermore, the drawing package for the Belt Drive Mechanism at the time of the critical design review is included in Appendix F.

5.2.1 Detailed Description of Belt Drive Design

This mechanism uses the friction of a wide conveyor belt to roll the tennis balls up an inclined surface and into a basket. In addition, a drive belt is used in order to provide a mechanical advantage and move the lifting belt more quickly. The purpose for this type of function is to compare which drive mechanism is more effective between the belt and the geared wheels in the Paddlewheel mechanism. The overall assembly consists of three subassemblies, each performing a different function. The first subassembly is the belt and frame assembly. This subassembly was the largest and most complicated of the model and is responsible for picking the balls up off the ground and rolling them up an inclined surface. In addition, the frame also provides structural rigidity for the entire model. The next subassembly is called the drive assembly. This subassembly consists of the mechanisms necessary to transmit the power from the wheels to the lifting belt using the mechanical advantage of a belt drive. The final subassembly is called the bin assembly. This assembly connects to the frame and stores the balls once they are lifted. This bin is able to be removed at any time to allow the user to store the bin and frame separately. The entire assembly can be seen below in Figure 11. Each of the three subassemblies are labelled in this figure.

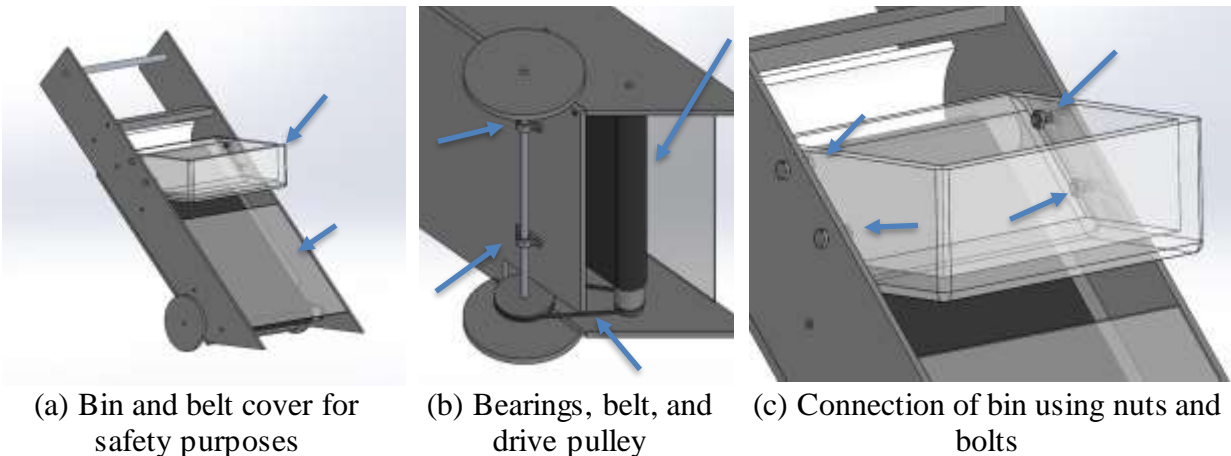


Figure 11. Subassemblies of Belt Drive Mechanism. Part (a) shows the belt and frame assembly, part (b) shows the drive assembly, and part (c) shows the bin assembly

5.2.1.1 Belt and Frame Assembly

As the largest subassembly in this model, the belt and frame assembly contain by far the most parts. First of all, the frame—consisting of two side plates and a backing plate—was constructed out of 3/8-inch sheets of HDPE plastic. Since the largest load on the machine is the tensile load required to keep the lifting belt taught, the HDPE plastic provided sufficient strength to keep the entire belt drive rigid. Next in the belt and frame assembly is the lifting belt itself. This belt is made out of oil-resistant neoprene and is supported on either end by conveyor rollers. The rollers for the final prototype are made of corrosion resistant galvanized steel. At the top of the belt, the belt and frame assembly contains a ramp made out of foam core and duct tape that guides the balls from the backing plate into the bin. Once the prototype was built, the team realized that it was also necessary to have a ramp in between the ground and the backing plate to help picking up the balls. This ramp is constructed of a plastic cutting sheet attached to the backing plate with screws. Additionally, a handle will be added to connect the two side plates and the top and will allow the

user to comfortably push the mechanism. To prevent the belt from flexing too much while tennis balls are picked up, we implemented a backing plate that is placed in between the belt. This backing plate also provides more rigidity in the overall body of the Belt Drive mechanism and can be seen in the figure below. As shown in Figure 11(a), either a clear plastic plate or any lightweight board will be placed above the belt in order to prevent any injury to anyone nearby.

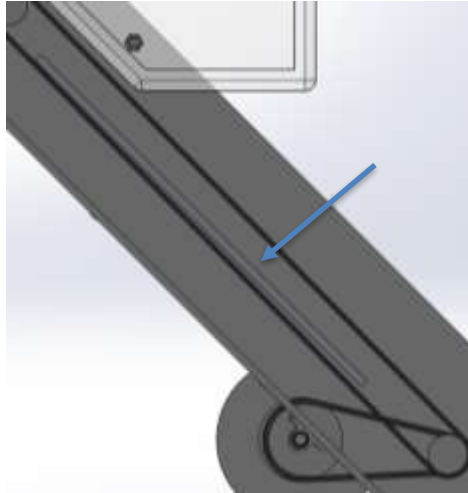


Figure 12. Cross-sectional view of belt drive showing stiffening mid-plate.

5.2.1.2 Drive Assembly

The drive assembly contains fewer parts than the belt and frame assembly, but the parts are slightly more complicated as they need to transmit the pushing power to the lift belt. The most critical part of this assembly is the drive shaft, which was manufactured out of steel. This shaft connects to two HDPE wheels on either side. Instead of directly transmitting the pushing power to the lift belt, an additional drive belt is used in order to provide a mechanical advantage that allows the lift belt to spin faster. This drive belt connects to the lower conveyor roller on one side, and a belt pulley connected to the drive shaft on the other. A cut away view of the model showing this lift belt can be seen below in Figure 13.

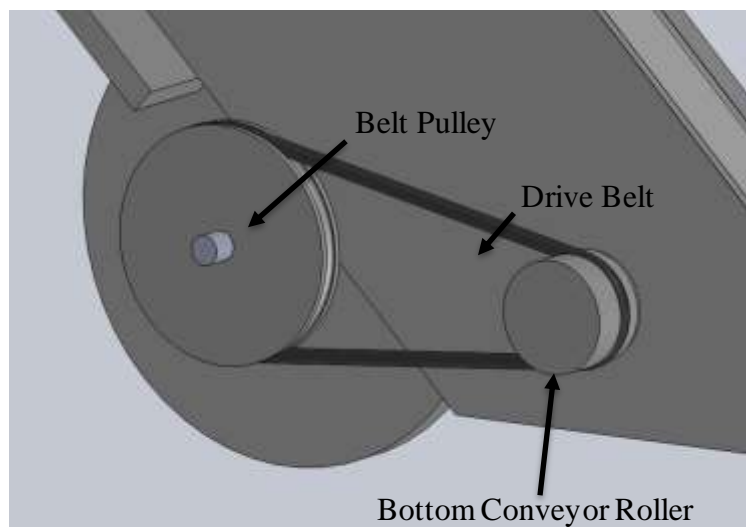


Figure 13. Labeled view of drive belt and attaching components

5.2.1.3 Bin Assembly

The bin assembly is the simplest subassembly, and it also contains the fewest parts. The function of this subassembly is to hold the tennis balls after they had been lifted, and then provide easy access to the balls once they have been lifted. The bin itself is made from a modified plastic bin and attaches to the side plates of the frame using bolts and nuts. This method of attachment allows the user to remove the bin from the frame for ease of storage and transport.

5.2.2 Analysis Description and Results

This model was unique in the fact that it did not require much analysis. The main design analysis included testing on the structural prototype to ensure that the belt would be able to pick up balls from the ground and start rolling them up the ramp. A CAD model of the structural prototype, as well as the physical prototype itself, can be seen below in Figure 14.

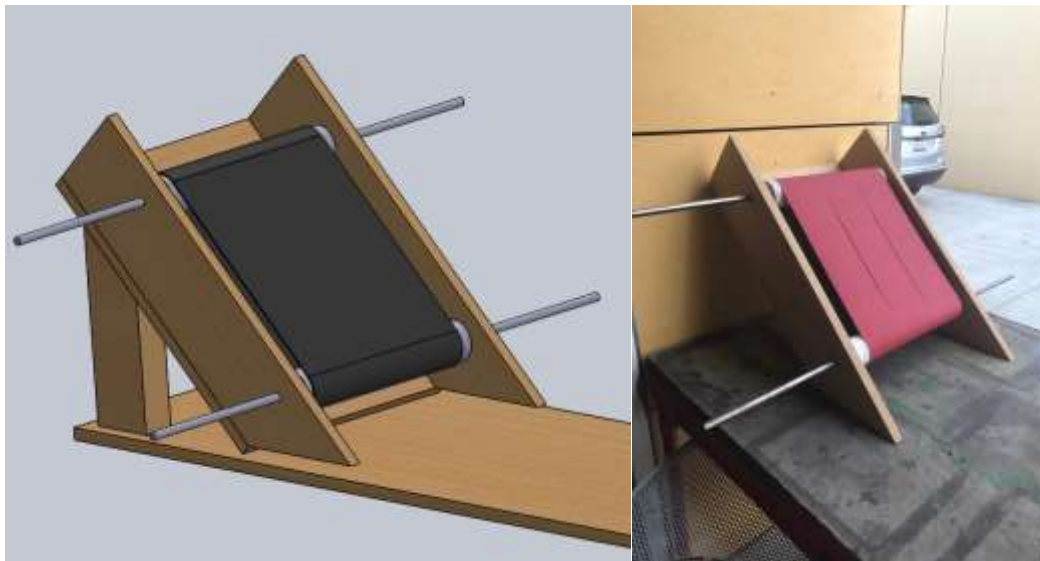


Figure 14. Structural prototype CAD model and physical model

The main challenge with the testing of the structural prototype was to ensure that two specific dimensions—in between the belt and the backing plate and the belt and the ground—were held constant at 2.5 inches. Since the diameter of a tennis ball is around 2.7 inches, this interference would allow the tennis ball to be pulled up the belt. A picture showing these two dimensions can be seen below in Figure 15.

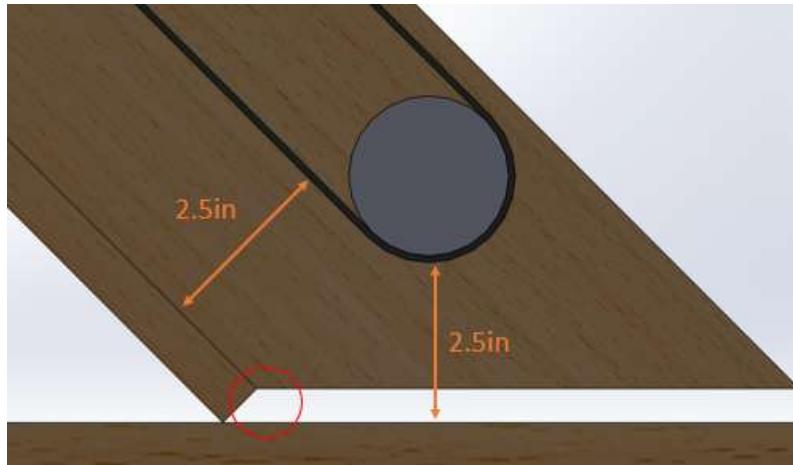


Figure 15. Cross-sectional view of structural prototype

During testing, the structural prototype was able to show a previously unforeseen problem. In the area between the ground and the backing plate, marked with a red circle in Figure 15, the tennis balls would get stuck as they had more than 2.7 inches of room. In order to fix this problem, sheets of paper were placed over the spot marked with a red circle, allowing the tennis ball to have a constant surface to contact in between the ground and the backing plate. This problem was fixed in the final prototype by attaching a cutting sheet to the bottom of the backing plate that would perform the same function as the paper shim.

5.2.3 Cost Analysis

While the entire Indented Bill of Materials for this model can be found in the drawing package in Appendix F, this section will cover some of the major purchased components for the final prototype. In order to allow the model to be more easily manufactured, the majority of the parts were purchased from vendors like McMaster-Carr. Although this made the final cost of the prototype slightly more expensive, it greatly reduced the time and effort required to manufacture the model.

Some of the most expensive parts of the model were used to construct the lift belt. This included the belt itself, the two conveyor rollers, and the alligator lacing used to connect the belt to itself. Since we purchased these parts in such low quantities, the costs were much higher than if the mechanism were being manufactured on a large scale.

The sheets of HDPE plastic were all bought from the same amazon vendor, Polymersan. By ordering sheets that are two feet by four feet and 3/8-inch thick, the cost of a single sheet was around \$60. However, one of these sheets was able to create up to 10 different parts.

5.2.4 Safety Considerations

The main safety consideration with this model was the unsafe nature of the moving lift and drive belts. Since these belts were spinning quickly, they could create high friction areas and pinch points. However, when consulting with a safety risk team, it was determined that the user would be unable to access these pinch points while they were using the mechanism. As a result, this safety concern was considered minor enough to be ignored.

5.3 Paddlewheel Mechanism

The paddle mechanism uses a self-powered paddle wheel to spin and pick up tennis balls. The paddle rotates as the mechanism is moving forward. However, when the mechanism is being pulled in reverse a two-way ratcheting system prevents the paddle from rotating. This is advantageous as it does not allow balls to be pushed back out of the mechanism. This design also implements a four-bar linkage system that is connected to the body supports and basket to allow for the basket to stay parallel to the ground as it is raised to its upright position as seen in Figure 16a. This assembly locks into both its lowered and raised positions by two spring-loaded pins through the upper linkage. The paddle mechanism is shown in Figure 16b.

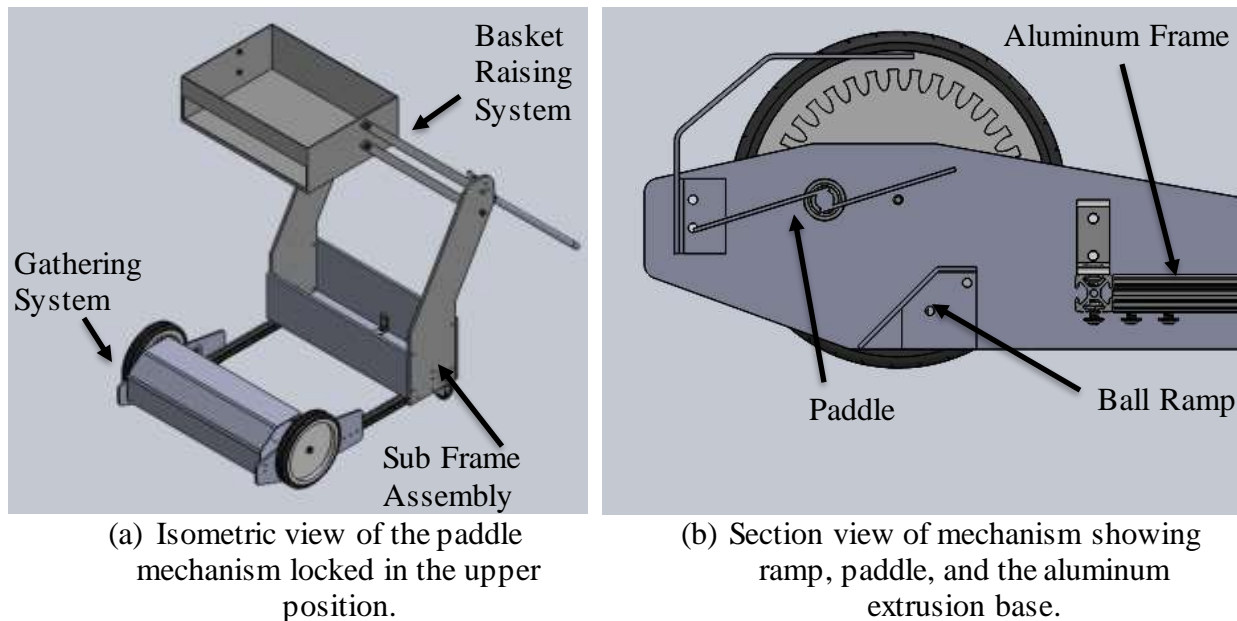


Figure 16. The paddle mechanism showing the two major functions in (a) raising tennis balls and (b) collecting/gathering the tennis balls.\

5.3.1 Sub Frame Assembly

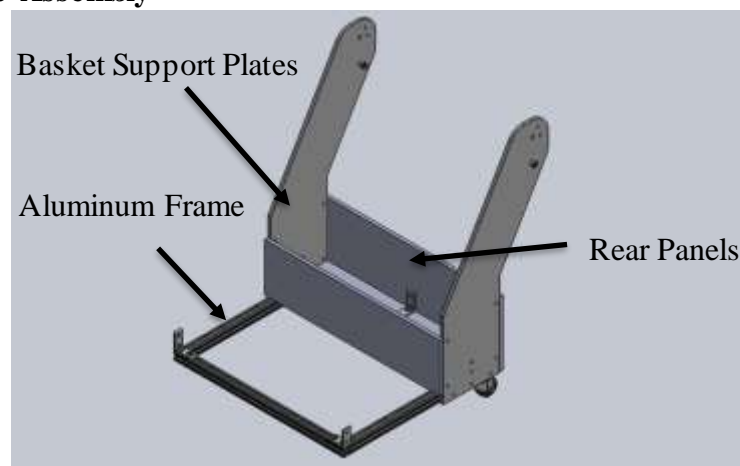


Figure 17. Sub Frame Assembly.

For the sub frame assembly, we used 10 series 8020 aluminum bars and 3/8-inch sheets of HDPE plastic. We wanted to have the added strength of the aluminum extrusion to be sure that the mechanism was rigid and strong. Additionally, we liked that the aluminum extrusion was corrosion resistant and provided us with plentiful mounting locations, making it ideal for our chassis.

5.3.2 Basket and Linkages

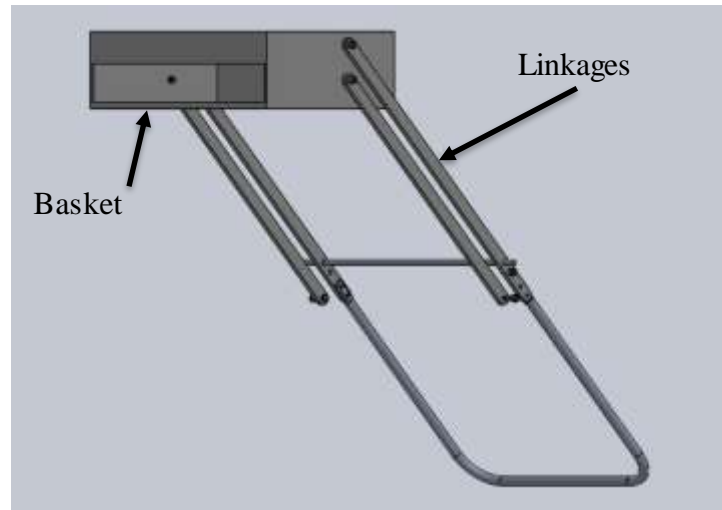


Figure 18. Basket Raising System.

The linkages attached act as a four-bar linkage system. The purpose of this assembly is to allow the basket full of tennis balls to raise parallel to the ground so that there is no tilt from the basket. In addition, the raising motion eliminates the need of the user to bend over to pick up the tennis balls. The bottom linkages and basket are made of plastic to reduce the overall weight of the mechanism. Although the top linkages were also made of plastic initially, these plastic linkages deflected far too much and were replaced with extruded angle aluminum stock. The actual handle that the user pushes is a repurposed lawn mower handle. The spring-loaded pins of our cable mechanism are directly mounted to the upper linkages. The side plates have two holes in them to lock the pins into at both the raised and lowered positions.

5.3.3 Drive Paddle Assembly

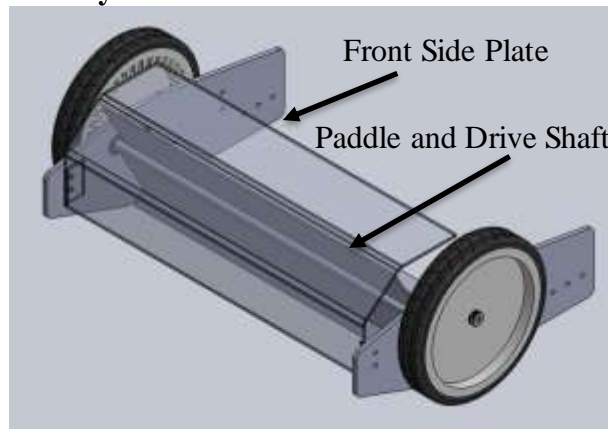


Figure 19. Gathering System Assembly

Our gathering system assembly is gear driven by a pinion gear connected to the internal gear teeth of the drive wheels. This drive system is commonly used in human-powered push lawn mowers and representations of the two components can be seen below in Figure 20.



Figure 20. Pinion Gear (Left) and Drive Wheel (Right)

The paddle component consists of a modified aluminum shaft that is faced on two sides so that two fins can be attached. The fins are made using a stiff polycarbonate core and a flexible rubber coating and tip. This configuration keeps the fins stiff enough to pick up balls but flexible enough to adjust for balls at odd angles. Additionally, the paddle wheel has a one way ratcheting system so that the paddle wheel is only driven when the mechanism is moving forward. For this to work, the shaft has two slots cut out about half an inch from the ends for the ratchet pawls to slide into and drive the pinion gears. As the mechanism is pushed, the paddle spins and collects tennis balls. When the user pulls the mechanism in a backwards motion, the wheels will spin but the shaft and paddle will not. Along with the drive wheels, we also used two castor wheels in the rear of the frame to help change the direction of the mechanism. In order to effectively lift the tennis balls from the ground up into the basket, there is a sheet metal ramp connected to the side plates that guides the balls into the basket.

5.3.4 Analyses and Results

For the paddlewheel mechanism, we had to do analyses on the size of the linkages and the distances between them. We wanted the linkages to not be too thick, but to also be made out of HDPE. For this, we started with simplifying our system and creating FBD's for each major component part as a way to track down the forces in each of the members. For our analysis, we gave a basket weight with balls of 15 pounds and offset the center of gravity to provide a safety factor within the linkages. The basket with 75 tennis balls should only weigh about 9 lbs, but we wanted to give a conservative estimate. We then calculated the forces and moments in each of the linkages so that we could determine the locations of maximum stress in the members. The results were such that the moment around the pivot point was calculated to be 144 lb-in. We then tried a few different linkage geometries before settling with 1" by 3/8". These dimensions give us a factor of safety greater than 4 and will allow our system to be stronger. Hand calculations can be seen in Appendix I.

An additional analysis we did for this mechanism was to build a small-scale prototype that could illustrate the 4-bar linkage system working as seen in Figure 21. From this prototype, we learned that it was very important that the arms remained parallel so that the box would remain completely

flat. We also learned that the linkages need sufficient clearance such that they do not run into each other and bind. We estimated that the user will only need to push the linkage system about 10 inches downward to raise the bin to a desired height.

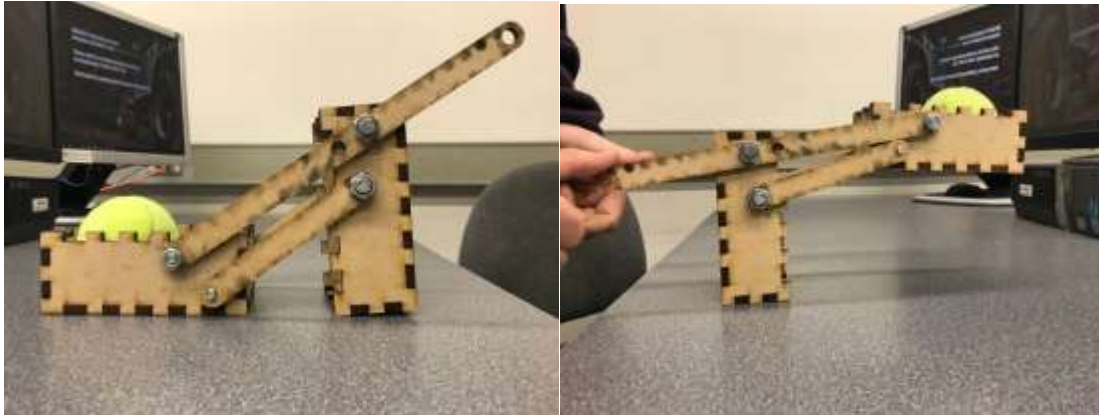


Figure 21. Four-Bar Linkage Structural Prototype

5.3.5 Safety, Maintenance, and Repair

In terms of safety for this mechanism, we considered adding a cover for our paddle wheel. We wanted to do this because the paddle wheel is a rotating shaft that could potentially cause damage to a consumer. However, similar to with the belt drive mechanism, we determined in a meeting with a safety team that the user is incapable of accessing the paddlewheel while the mechanism is being pushed. As a result of this, this safety concern was considered trivial and the paddle cover was taken out. Since this mechanism is gear driven, there are not a lot of components that need additional maintenance requirements. The paddle wheel is supported by sealed ball bearings on each side as a means to make them less susceptible to the outside environments. Unfortunately, this means that the user is not able to maintain them. Instead, the user will have to replace them when they eventually wear out. We decided that the benefits of the sealed bearings outweighed the costs as it meant the mechanism would be operating smoother for a longer period of time before part replacement was necessary. In order to replace the bearings, they will need to be popped out of the side plates, and new ones will need to be pressed in to the holes.

5.3.6 Cost Analysis

All of the components that go along with the assembly of the paddlewheel mechanism were purchased. The indented bill of materials shown in Appendix F gives us a rough estimate of the total cost for the mechanism, which is approximately \$400. The bulk of the cost comes down to the combined HDPE material which was purchased in two sheets of 24"x48" dimensions from Amazon. This combined cost includes all four original linkages, the side frames, the side plates, and the bin. For the two sheets, the combined total was approximately \$120.

All other components included in the mechanism were purchased through a variety of vendors. The fasteners and T-Slot frames were purchased from McMaster-Carr as well as the spring-loaded pins. The 80/20 t-slot frames were purchased as one 10-foot long piece that was cut down to individual pieces for the base frame of the mechanism. This single piece was priced around \$31.

The driving system that includes the drive wheels, pinion gears, and ratchet pawls, were acquired through a push mower that was purchased online from an individual. The included costs for these parts from an online seller came out to be about \$50. However, if these parts were purchased on a larger scale, the costs would be decreased dramatically. We initially purchased a basket from Target and tried to modify it to meet our goal of collecting tennis balls. After making changes to the overall dimensions of the design, the basket was not a good fit and so we created a bin made of HDPE instead.

5.4 Paddlewheel Mechanism Design Changes



Figure 22. Updated Paddlewheel Mechanism

After the two final prototypes were tested and the paddlewheel was chosen, the team found that there were still areas of the prototype that needed to be modified to get the mechanism to function more efficiently. Since this point, we have made changes to the basket, linkages, and structure of the prototype that we will outline in this section.

5.4.1 Basket Update

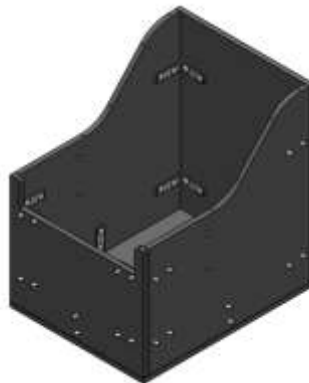


Figure 23. Updated Basket made from HDPE.

Our initial plan for the basket called for a box with an opening on the front side that allowed for balls to enter inside. We implemented a folding brush cover that acted as a gate to trap the balls inside of the basket. Through our testing, we found that the bristles of the brushes were not strong enough to keep the balls in the basket, and that after the first row of the basket was filled, it was difficult to get any more balls inside. This issue caused the balls to ricochet off of the basket surface and not make it inside. To combat this, we developed a new basket mounting scheme that lowered the basket location and increased the ramp height. Lowering the basket allowed for more balls to fill the basket and increasing the ramp height allowed for multiple ball layers to fill within the basket. A future change to this would be to get a custom wire box made for the prototype. This would be advantageous as it would decrease the overall weight of the mechanism.

5.4.2 Linkage Update



Figure 24. Basket Raising System Sub Assembly

As discussed earlier, all four linkages were originally designed to be made from water jet cut HDPE plastic. However, when these linkages were used on the final prototype to raise the basket, they deflected around five inches vertically. Since this was far more deflection than was acceptable, the material for the top linkage was changed to extruded angle aluminum stock. This new bracket was much stiffer and was able to reduce the deflection to around ½-inch.

5.4.3 Structure Update to Sub Frame Assembly and Gathering System Assembly

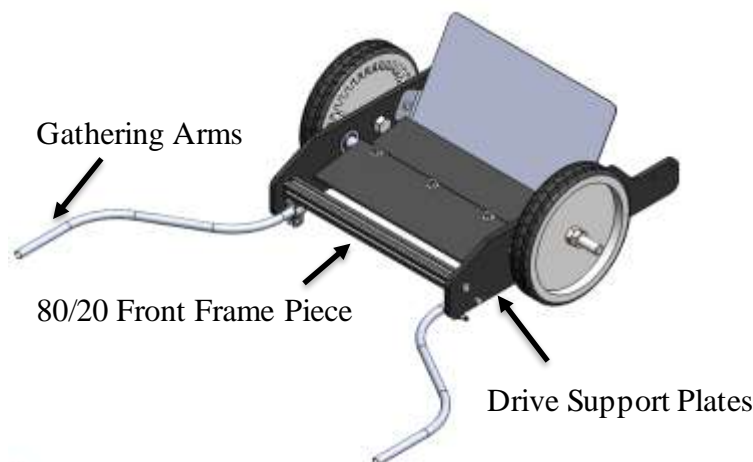


Figure 25. Updated Gathering System Assembly

The problem with the structure of this mechanism arose when the basket was being lifted to height. When this would happen, the bin would run into the front 8020 bar of the frame, as well as the body drive support plates. Initially, this problem was fixed by removing that bar altogether. However, this caused the mechanism to become very flimsy and unstable when in use. As a result, the same 8020 piece was added back to the mechanism, but this time in the very front of the mechanism. This maintained the stiffness of the mechanism while also allowing the bin to be lifted freely. Changes to the body support plates were made so that the basket would clear them while raising and to keep them further from the ground. We found through our testing that the initial drive support plates were too close to the ground and would occasionally drag. We also modified the gathering system to incorporate arms that would allow for the device to direct the balls into the paddle wheel and increase the ease of picking up balls near the net and fence.

5.5 Overall Cost Analysis

The overall budget for the project is \$1400. For the Belt Drive mechanism, the overall procurement was \$403.71. The Paddlewheel Mechanism budget cost is currently at \$262.80. This sets the remaining budget at an amount of \$733.49. It is important to note that many changes were made during the last phase of our project timeline and since most of the changes were minor, some parts were purchased by each team member throughout the last quarter. This will have a slight change in the overall cost of the final design of the Paddlewheel Mechanism but the difference is not significant. Many of these minor changes were purchases of hardware needed. The remaining amount leaves us well under the starting budget that can also be used to improvise the current design if a second iteration of this project were to occur.

6 Manufacturing

This section will highlight the parts manufactured for each of the prototypes by our team. It will cover both the materials used and the manufacturing processes selected as well as the reasons behind each of these choices. While both prototypes were built to a final prototype, we soon selected the paddlewheel mechanism as our final design after some testing of each of these prototypes. After this selection, the team continued to make changes to the paddlewheel prototype.

As a result, the manufacturing of the paddlewheel mechanism is slightly more extensive. In addition, our future recommendations for manufacturing will only pertain to the paddlewheel mechanism.

6.1 Belt Drive Mechanism

As discussed before, the belt drive mechanism was constructed mostly from purchased parts. An overview of the manufacturing plan for both the purchased and manufactured parts of the model will be described in the sections below.

6.1.1 Procurement

The following section will discuss where each of the purchased components for the Belt Drive Mechanism were purchased from. For a more in-depth look at all of the purchased parts of this model, refer to the Purchased Part Detail List in Appendix G. This list contains website references to the data sheets of all of the purchased parts.

6.1.1.1 McMaster-Carr Parts

The large majority of the parts for this model were purchased from the online part supplier McMaster-Carr. A full list of the purchased parts and costs of parts from this manufacturer can be seen below in Table 4.

Table 4. Purchased parts from McMaster-Carr with costs.

Part Name	Cost
Conveyor Roller (x2)	\$25.48
Lift Belt	\$51.28
Alligator Lacing	\$46.38
Drive Belt 21.5"	\$4.35
Drive Belt 23"	\$9.57
Bearing Mounts (x2)	\$7.40
Key	\$0.68
Belt Pulley	\$20.75
Bolts (x4)	\$21.76
Hex Nuts (x4)	\$25.44
Lock Nuts (x4)	\$27.44
Screws (x12)	\$21.76

While parts from McMaster-Carr were slightly more expensive than other suppliers, the ease of purchasing almost all of the parts from one supplier was incredibly convenient.

6.1.1.2 HDPE Sheets

As stated before in Section 5.2.3, each of the 3/8-inch HDPE sheets were bought online from Amazon. Two sheets of two foot by four foot sheets were enough to construct the entire prototype, and each of these sheets cost around \$63.

6.1.2 Manufacturing

In the following section, the manufacturing required to produce the final prototype of the belt drive mechanism will be discussed.

6.1.2.1 HDPE Sheets

The majority of the manufactured parts were cut from blank sheets of 3/8-inch thick HDPE plastic. The manufacturing associated with these parts simply included using a water jet cutter to cut the blank sheets to the right dimensions with the right holes. The water jet cutter belongs to the Cal Poly IT Lab. Using the water jet cutter not only made the manufacturing process easier by making it almost completely automated, but it also gave the parts a nice smooth surface finish. This manufacturing process was also used for the Paddlewheel Mechanism.

6.1.2.2 Drive Shaft

The drive shaft required the most extensive manufacturing by our team. In order to allow the fitting of the belt pulley, part of the shaft was turned on a lathe to a specific diameter, and then a mill was used in order to create a keyway to attach the pulley to. One challenge for this part was how to fix the shaft in order to mill the keyway. In order to fix this problem, spacers and a clamp was used to hold the shaft still while the milling operations were done.

6.1.2.3 Ramp

The ramp at the top of the lift belt was constructed using foam core and duct tape. These parts were incredibly cheap and easy to manufacture. In addition, they proved sufficient until the two final prototypes could be tested and the paddlewheel was chosen. If the belt drive mechanism was chosen, we would have refined the design, and these materials would have been changed to a more permanent solution.

6.1.3 Assembly

While the model was entirely constructed by hand, the order that each part is assembled was critical. In order to ensure that these parts were assembled in the correct order, an assembly flowchart was followed. This flowchart can be seen below in Figure 26.

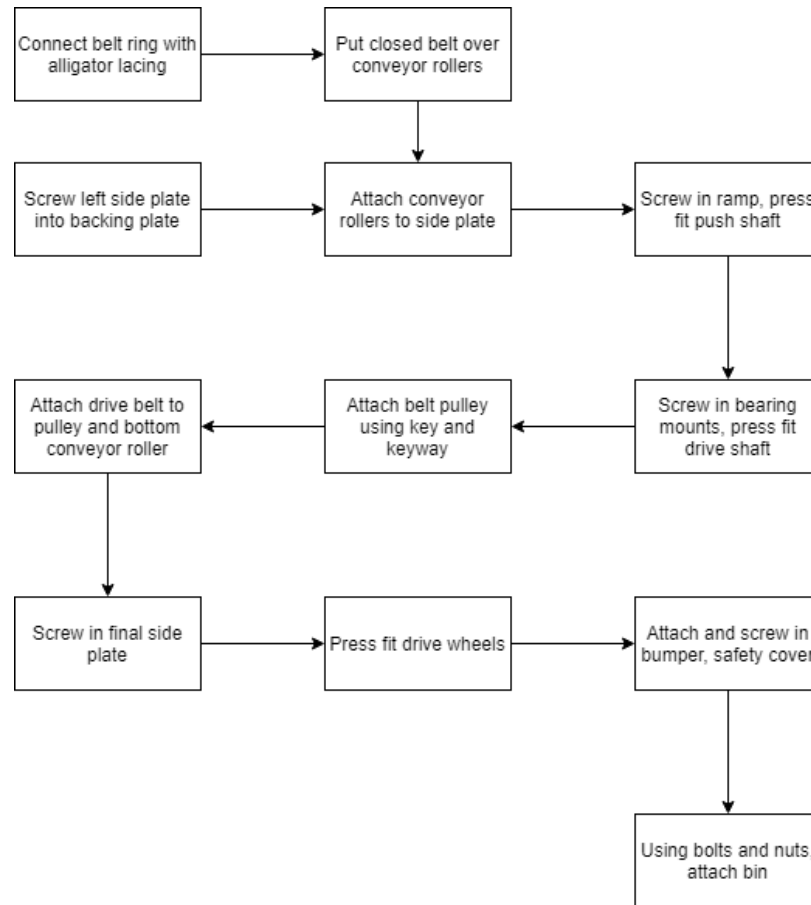


Figure 26. Assembly flowchart for Belt Drive Model.

One of the most significant challenges with the assembly of this model was attaching the conveyor rollers to the second side plate. This was difficult because the conveyor rollers had to be stretched enough to provide tension in the belt. This problem was solved by having two team members stretch the rollers apart until they would both fit into the holes in the side plates.

6.2 Paddle Mechanism

As previously discussed, we manufactured all of the flat HDPE sheets and linkages of the paddle wheel mechanism. However, we still purchased as many parts as possible from outside vendors and suppliers.

6.2.1 Procurement

For the paddle wheel mechanism, we purchased parts from McMaster-Carr, Amazon, and Home Depot. We would have needed to spend approximately \$40 on our drive system (ordered from sears), and an additional \$20 on our handle bar (from repairclinic.com), but we were able to find them used locally for a lower cost for this prototype. However, as we continue on in the manufacturing process, we will need to order these parts for future builds. A majority of the hardware required for this design can be purchased through McMaster-Carr and can be seen outlined in Table 5. From the table you can see that we will be spending \$125 at McMaster-Carr.

Table 5. McMaster-Carr Parts.

Part Name	Cost
Retractable Spring	\$21.54
Brush holder	\$7.51
Brushes(x2)	\$13.17
80/20 10ft	\$16.00
Aluminum Shaft 6ft.	\$21.13
Castor Wheels	\$8.80
T-slot fasteners	\$16.10
T-slot anchors	\$13.56
Total	\$117.81

6.2.2 Manufacturing

The manufacturing steps necessary to complete the final paddlewheel prototype were slightly more extensive than those necessary for the belt drive. This is because the paddlewheel mechanism was built in order to make the final selection between prototypes, and then continually modified to increase the efficiency of the mechanism. All of the manufacturing steps required are described in the section below.

6.2.2.1 Flat sheet pieces

The parts of this design that are made out of 3/8-inch HDPE sheets are the body drive support plates, lower arm linkages, body basket support plates, the basket and basket mounts, and the rear body plate. All of these parts were manufactured utilizing a water jet cutter. Figure 27 shows a picture of the water jet cutting process.



Figure 27. HDPE Water Jet Cutting

The HDPE sheets provide a variety of benefits over aluminum, steel, or wood. Some of these include the facts that it is incredibly easy to manufacture with a water jet cutter, lightweight, and stiff enough to provide structural support. Additionally, the HDPE will withstand the elements

better as it will not corrode. The ease of manufacturing of these sheets allowed us to make updates and changes to our prototype by easily modifying our CAD files.

6.2.2.2 8020 Frame

The frame for the paddlewheel mechanism was designed and built from 8020 aluminum t-slot bars. This material was chosen because it is both acceptably stiff and incredibly easy to manufacture and modify. Additionally, this material gave us flexibility with mounting as we were able to slide bolts along the slots. These bars were cut to length using a horizontal band saw then holes were drilled in the cross rails using the mill. Once each piece was manufactured, they were assembled together to form the frame of the mechanism as part of the Sub frame assembly. These processes can be seen below in Figure 28.



(a) Holes Drilled for Assembly.



(b) Assembly of Frame.

Figure 28. Manufacture and Assembly of 8020 Frame.

6.2.2.3 Paddlewheel Drive Shaft

The paddle wheel drive shaft was our most time-consuming part to manufacture. In order to create the shaft, it first was cut to length using a horizontal band saw. Next, a manual lathe was used to face the ends to a precise length and turn down the end diameters to allow bearings to be pressed in place. After this, a mill was used to create slots in the ends for the ratchet pawls and face the top and bottom surfaces flat to allow for paddle attachment, as well as drill holes through the shaft in order to attach the paddles. Some images from this manufacturing can be seen below in Figure 29.



(a) Slots drilled for ratchet paws.



(b) Flats milled for paddle attachment.

Figure 29. Manufacture of paddlewheel drive shaft.

One of the main challenges of this part was the large amount of manufacturing time necessary to create the part. Since three different machines were used to create the part, it took our team members around four hours to complete manufacturing of the shaft. While this was not detrimental to our project, it is important to recognize that this machine time might become a problem if and when the product is brought into mass production. Additionally, we ran into trouble creating the slots for the ratchet paws but we think that this could be corrected if we had the proper size end mill, or possibly a broach to create the pocket.

6.2.2.4 Linkages

While the original plan was to manufacture all four linkages out of HDPE plastic, it was soon determined that the load from lifting the basket caused a significant deflection in the linkages. In order to alleviate this problem, the top linkages were manufactured from extruded angle aluminum. Since these top linkages became much stiffer than the bottom linkages, they were able to hold the majority of the load from the basket. In addition, the increased stiffness was able to drastically reduce the deflection problem by limiting the maximum deflection to around 1/2-inch.

6.2.2.5 Tennis Ball Bin

Throughout the design process, our bin underwent a number of different iterations. Initially, the bin was manufactured by modifying a store-bought plastic storage bin by cutting a slot in the bottom. Brushes were then attached to the slot to allow balls to enter the bin, but to prevent them from exiting. This bin had a variety of problems. First of all, the brushes were unreliable and would often keep balls from entering the bin and spit them back out. Also, once the bin filled with one layer of balls, those balls would also prevent other tennis balls from entering the bin. This problem was fixed by redesigning the bin to have an open top and allowing balls to pop into the top of the bin. The first bin manufactured for this purpose was made from spare wood parts to show the functionality of this concept. Once the concept was proven, the bin was remade from water jet cut HDPE sheets. The bin was assembled using brackets and bolts to connect each of the HDPE panels. The final bin can be seen in Figure 30.



Figure 30. Final HDPE bin.

This provided a bin that was not only sturdy, but also matched the aesthetics of the rest of the mechanism.

6.2.2.6 Ball Ramp

The ball ramp that transfers tennis balls from the paddle into the basket was made from 0.020-inch steel sheet metal. This sheet metal was cut into the correct dimensions and then two flanges were added to the sides in order to connect the ramp to the HDPE panels on the sides. However, a problem arose when initially testing out this sheet metal ramp: the metal was far too thin and would deflect significantly when tennis balls were pushed into it. Our team attempted to solve this problem by folding over the ends of the ramp into 180-degree tabs to add stiffness, but the problem was still there. As a result, a piece of plywood was attached to the back of the ramp using duct tape. Figure 27 below shows the temporary solution for the ball ramp in both a functional position and a folded-over position for storage.



(a) Ramp in functional position.



(b) Ramp in folded position for storage.

Figure 31. Temporary ball ramp in various positions.

Although this solved the problem, it is not aesthetically pleasing and obviously not a viable solution for a mass-produced product. In order to fix this problem more effectively, a sheet metal with a larger thickness such as 1/8-inch sheet metal, should be used. This will remove the deflection problem while also improving the beauty of the mechanism.

6.2.2.7 Connecting Hardware

As the prototype was assembled, many different types of connectors were used in order to hold the mechanism together. For the majority of functions, including attaching the linkages, spring-loaded pins, and the handle to the frame, bolts with nylon locknuts were used. Additionally, brackets were used to connect the HDPE bin as well as some of the HDPE frame pieces. These brackets were used because drilling holes and inserting screws into the plastic often resulted in a bulge in the plastic and a less-than-optimal hold. Finally, the 80/20 frame was assembled using 80/20 anchors, and the body plates were attached using bolts and t-nuts.

6.2.3 Assembly

For the Paddlewheel mechanism, the entire system was assembled in the three sub-assemblies mentioned in Section 5.1 (sub frame assembly, basket raising system, and gathering system assembly). The main chassis and the drive paddle assembly needed to be assembled in a specific way as to be sure that all parts would be able to be attached correctly. For sub frame assembly, the flowchart of Figure 32 was followed to ensure that it is assembled correctly. For the gathering system assembly, the flowchart of Figure 33 needed to be followed. Once these two subassemblies were assembled, the basket and linkages assembly could be added on top.

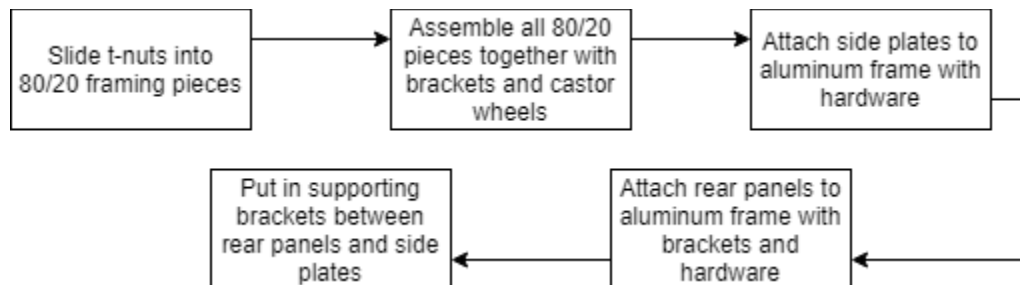


Figure 32. Flowchart for sub frame assembly.

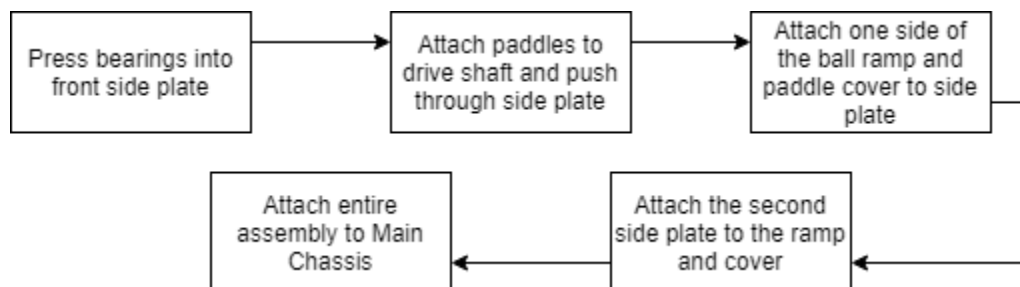


Figure 33. Flowchart for gathering system assembly.

7 Design Verification

For each model, the structural prototype was used to conduct testing for at least one function of the model; however, the next prototypes will be fully functional and will be used to conduct further testing on the models. In order to document our tests and results, a Design Verification Plan and Results (DVP&R) table was constructed. Using the DVP&R table, our team was able to plan when each of these tests will be conducted, as well as who will be in charge of each test. The entire DVP&R table can be found in Appendix K, but description of some of the individual tests can be found below.

7.1 Paddlewheel Mechanism Tests

There were five critical tests that we wanted to accomplish to ensure a functioning and reliable working prototype. These tests are listed and described below.

7.1.1 Ease-of-Use Test

The ease-of-use test was performed to collect data on how much force a user would need to push the Paddlewheel mechanism. The equipment used for this test was a push/pull gauge, in particular, an Omega DFG35-100 shown in Figure 34 below. The test was performed with four different amounts of tennis balls in the bin. There were four trials that ran for the different amounts of tennis balls and the force was collected for each trial. It is important to note that while we ran this test, there were a few times that tennis balls jammed up against the ramp. This jamming of tennis balls caused the force gauge to increase, but the change was not significant enough to skew our data. Also, we noted that more jams were caused when the mechanism was pulled at a lower speed than when pulled at an average walking speed of approximately 3ft/s.



(a) Force Gauge DFG35-100.



(b) Position and angle used for pulling the mechanism.

Figure 34. The force gauge was used in a pulling motion due to the difficulty of pushing the mechanism.

The test was setup with 20 tennis balls lined up in a 10-foot span and randomized as single or double tennis balls. Figure 35 shows a section of the actual setup and how the device was utilized to perform the test.



(a) Test setup before the test begins.



(b) The paddlewheel mechanism in motion as it collects tennis balls.

Figure 35. The Ease-of-Use test being performed by team member George.

The table below shows the data that was collected. The number of tennis balls jammed are noted in parentheses next to the force that was recorded.

Table 6. The forces recorded during the ease-of-use test including the number of balls jammed or overshot in parentheses during each trial.

# of Tennis Balls	Trial 1 [lbf]	Trial 2 [lbf]	Trial 3 [lbf]	Trial 4 [lbf]
0	11.2 (0)	11.0 (1)	13.2 (0)	15.2 (1)
20	12.4 (0)	12.1 (1)	10.3 (1)	10.4 (1)
40	14.4 (2)	18.6 (2)	17.8 (1)	17.4 (2)
60	14.4 (0)	14.1 (1)	11.3 (0)	14.0 (0)

Additionally, since this test was the one that contained the most numerical observations, a short statistical analysis was performed on the results. This involved finding the average and standard deviation of the set of data. The average was determined to be 13.4 lbs. and the sample standard deviations was 2.7 lbs.

7.1.2 Transportability Test

The transportability test was important to perform because it was able to show us how quickly the prototype could be collapsed to its storage form. Currently, the hardware used are standard nuts

and bolts. This was taken into account as we needed to record the time it took to perform each step in collapsing the mechanism. The first step was to disengage the locking pins so that the user can rotate the bin up to a horizontal position. Next, the user is to remove the bolts that hold the handle up so that the handle is able to come down and rest against the two upright plates of the mechanism. During this step, the ramp is also moved and rotated over the paddles. The third step is to loosen the bolts that connect the two front side plates so that the subassembly with the two large wheels can slide towards the handles. Figure 36 shows the steps described above.



Step 1



Step 2



Step 3



Step 4

Figure 36. Steps required for collapsing mechanism.

Once all steps were completed, the final collapsed mechanism was measured to be 12.4 cubic ft. in volume and is shown below. The overall time it took to collapse the mechanism was 238 seconds, or 3 minutes 58 seconds.



Figure 37. Collapsed paddlewheel mechanism with a volume of 12.4 cubic ft.

For a more detailed manual on how to collapse the mechanism, refer to the Operators Manual in Appendix L.

7.1.3 Linkage Deflection Test

The linkage deflection test proved to be a critical test because our original linkages were not able to withstand the loads being applied. The initial linkages were made of HDPE and as mentioned above in the manufacturing section, the modification was to replace those two top linkages to aluminum linkages that were more rigid and able to withstand higher loads. The deflection test was performed by having the bin in a horizontal position, parallel to the ground. Having the bin at this position will create the maximum deflection at the end of the linkages where the bin is located because the load is not applied axially on the linkages. The deflection was measured from the ground up to the top of the bin as shown in Figure 38 below.



Figure 38. Team member Tyler measuring the deflection with 20 tennis balls in the bin.

The test was performed five times with the following amounts of tennis balls: 10, 20, 30, 40, and 50. The table below shows the data collected while performing the linkage deflection test. It is

important to note that while the bin shown is made of wood, the modified bin made of HDPE weighed approximately the same. The initial height with no tennis balls was measured at 20 ¼ inches.

Table 7. Linkage deflection data collected

Tennis Balls	Deflection [in]
10	20-1/8
20	20-1/16
30	19-15/16
40	19-3/4
50	19-5/8

The maximum vertical deflection of the bin noted was measured to be ½-inch.

7.1.4 Gathering Efficiency Test

The gathering efficiency test was one of our final tests performed once our working prototype was complete. This efficiency of gathering the tennis balls depended on the amount of errors that were observed. Errors in this test were defined as tennis balls jamming up against the ramp more than once and tennis balls that overshot or missed the bin. The following equations was used to determine the efficiency of our mechanism.

$$\eta_G = \frac{\#TB - \#Errors}{\#TB}$$

where $\#TB$ is the total number of tennis balls used, $\#Errors$ is the number of tennis balls not picked up, and η_G is the gathering efficiency. For this test, team members Alex and George each performed two trials. Figure 39 shows the setup of the gathering efficiency test and the collecting of tennis balls.

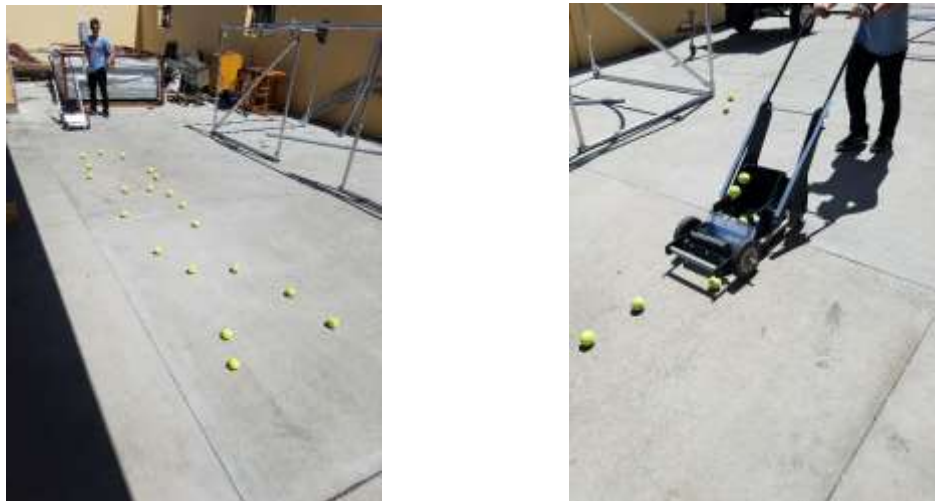


Figure 39. Team member George performing the gathering efficiency test.

The data collected is shown in Table 8 below. The overall average percentage of collecting tennis balls by the Paddlewheel mechanism was satisfactory per the required criteria the team set before accomplishing the gathering efficiency test.

Table 8. Gathering efficiency data collected.

Trial	#TB	#Errors	η_G
1. George	20	4	80%
2. George	20	4	80%
3. Alex	20	5	75%
4. Alex	20	2	90%

7.1.5 Ball Capacity Test

The ball capacity test was created to meet the criteria of holding 65+ tennis balls. This test was simple and straightforward. The team simply placed tennis balls into the bin made of HDPE until it was full. The filled capacity of the bin was recorded as 70 tennis balls.

7.1.6 Challenges and Test Limitations

There were some challenges that came along while performing these tests on the Paddlewheel mechanism. First, the ramp was made from very thin sheet metal and when testing began, the tennis balls were being jammed up against the ramp which caused some bowing of the sheet metal. Another challenge that the team came across was the lifting of the bin with the four-bar linkage system. Also, while performing the transportability test, the time it took to loosen and remove the bolts and nuts was higher than expected. These issues are outlined and described with future solutions in the Project Management section [8.2]. The only test limitations that we had was with the force push/pull gauge. Initially, we wanted to have the ability to actually push our mechanism with the gage, but this was awkward and provided erratic results. To fix this problem, the gage was used as a pull gage and a hook was used to attach the gage to the handle.

8 Project Management

The overall design process began with background research on existing designs and techniques for gathering tennis balls. We then focused on understanding and defining the customers' needs. The team began with initial ideas of conceptual models throughout the ideation phase. After building conceptual models, the team selected a few designs that allowed us to move forward and begin building functioning conceptual prototypes to then benchmark against the specifications we had outlined. The preliminary design review was then completed and presented to our peers before it was presented to our sponsor. This preliminary design review was a report that is continued from the scope of work. It consisted of a written report, an oral presentation, and a conceptual prototype. After this review, the team used information from the conceptual prototypes to develop final prototypes for each of our two concepts. The critical design review came next once the team had determined exactly what would go into the final prototypes. This included solid models, lists and prices of all ordered and manufactured parts, and build plans. Similar to the preliminary review, this critical design review consisted of a written report and an oral presentation to the class and the sponsor. After this review, the two final prototypes were built and tested to show functionality. After conducting some preliminary tests, it was decided by both the project team and our sponsor

that the paddlewheel mechanism would be our final design, and that concept was progressed. In preparation for the final design review, the final prototype was tested and continually modified as challenges arose. Although many of the challenges were identified and fixed, some of these challenges required too much time to fix and were found too late in the design process and were unable to be completed before the final design review. The problems that were unable to be solved can be found below in the Next Steps section. For the final design review, the senior project team presented the final prototype at Senior Project Expo with an accompanying poster that outlined the design process. Additionally, this final design report was compiled in order to more comprehensively outline the design process throughout the project.

8.1 Gantt Chart

In order to better organize the key deliverables shown above in Table 6, the team also created a Gantt chart using TeamGantt. With the use of this chart, the team knew approximately how long each deliverable would take to complete, any dependencies between deliverables, and who was in charge of each deliverable. In order to stay on track, the team updated the Gantt chart weekly with deliverables for each week. The full Gantt chart can be seen in Appendix M.

8.2 Deviations from Original Plan

While the project has gone largely according to plan, there have been various changes throughout the process that have required our team to make on-the-fly changes. Some of these changes are discussed in the section below.

8.2.1 Progression to Two Final Prototypes

Initially, our team believed that by the time of our preliminary design review, we would have narrowed the number of our designs to one. However, after an early meeting with our sponsor Professor Chen, we discovered that he wanted us to progress our two final designs until both final prototypes were built and could be tested. This provided some unique challenges for our team. Most importantly, it doubled the amount of work we needed to do by having us develop two ideas. In retrospect, this increased work led to some of the smaller design problems that arose later down the road with our paddlewheel mechanism. If we were able to devote more time to the initial design process of that mechanism, the team might have been able to catch those design issues before building the final prototype.

8.2.2 HDPE Ordering Issue

Initially, the team planned to order all of our HDPE plastic from the supplier Interstate Plastics. However, we soon realized that the shipping time from this company was around six weeks. Since that would severely disrupt our planned schedule, we decided to find a separate supplier. Fortunately, we were able to find HDPE sheets with the same thickness on Amazon for an even cheaper price. Although these sheets were smaller, we simply ordered enough to account for all of our parts and had the sheets within a week.

9 Conclusion

The full project of a lightweight tennis ball pick-up and hopper proposed by Professor Chen at Cal Poly, SLO is presented in this document with background research, objectives, and the process

that was taken to implement the design. The main goal was to deliver a product that was lightweight, inexpensive, and durable. While two designs were progressed until the final prototype stage, the paddlewheel mechanism was ultimately chosen as the final design because of its reliability. After this decision was made, the team performed various tests on this final prototype in order to gain concrete data on how well the mechanism performed. All of this data is represented in and interpreted in this report. Additionally, the team continued to make changes to the mechanism to increase its efficiency and aesthetic appeal. With the limited amount of time for the project, not every desired design change was able to be implemented. As a result, some recommendations for additional changes are outlined in the Next Steps section below. At its final stage, our prototype is fully functional and ready to be used by any potential consumer. However, in order to make the product more suitable for mass production, it is recommended that these Next Steps be taken first.

9.1 Next Steps

While our final prototype completely proves our paddlewheel concept and its viability as a final solution, the prototype still has a few problems that need to be addressed before it will be ready for production. These problems and recommended changes for solving these problems are outlined below.

9.1.1 Connecting Hardware Problem

The mechanism is collapsible so that the user will be able to fit it in a car or storage space. However, the final prototype requires that the user use two wrenches in order to collapse both the mechanism and the frame. Although this is possible, it is both incredibly time consuming and unrealistic to assume that the user will have two wrenches with them at all times when trying to store our product. In order to fix this problem, it is recommended that these nuts and bolts be replaced with wing nuts and wing bolts. This way, the user will be able to collapse the mechanism faster and with only the use of their hands.

9.1.2 Collapsible Handle Problem

In order to reduce the amount of parts that needed to be manufactured, a handle was chosen from a previous lawn mower that also provided us with the wheels and pinion gear. Although this handle serves its function of allowing the user to comfortably push the mechanism, it has a very obvious problem when the user tries to collapse the handle for storage. The base of the handle where it connects to the frame is curved, and thus it is very awkward to try to tighten or loosen bolts onto this curved surface. Fixing this problem will be simple and will involve manufacturing our own handle that is flat at the base instead of curved.

9.1.3 Linkage Pin Problem

There are two problems with the spring-loaded pins that lock the linkages into place on the frame. The first problem is that the pins are currently extending straight into the HDPE frame. Although this temporarily shows the functionality of the pins, it is slowly warping the area around the pinhole on the plastic from the load of the bin. In order to solve this problem, metal collars can be attached to the plastic frame with holes for the pin at specific heights. This will hold the pin securely while transferring the load over a more distributed area and preventing plastic warpage. The second problem is that currently, the pins must be pulled out at two spots. As a result of this, the process

of lifting the bin requires two people: one to push the handle and one to adjust both of the pins. This problem can be solved by flipping the spring-loaded pins around so that they are released inward instead of outward. Then, a cable can be attached to the two pins and run up to a lever attached to the top of the handle. This way, the user can pull the lever to release the pins and then push the handle to lift the bin without the need for a second user.

9.1.4 Tipping Problem

Another problem arises when the user tries to lift the bin using the handle: the mechanism begins to tip backwards. Currently, the problem is alleviated by having another user hold the front of the mechanism so that it does not tip. Obviously, this is not a viable solution as it is unreliable and requires another user to lift the bin. In this instance, the mechanism is essentially a lever with the force being applied to the handle, the load at the bin, and the fulcrum at the rear castor wheels. The tipping problem can be solved by moving the fulcrum to increase stability in the system. This can be accomplished by extending the 8020 frame back beyond the rear plastic sheet and attaching the castor wheels farther back on the frame.

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[4] “What to Do with 325 Million Tennis Balls Per Year.” *Sustainable City Network*, 16 Mar. 2016, www.sustainablecitynetwork.com/topic_channels/public_works/article_16805af2-eb8a-11e5-bc48-af9208f621b2.html.

[5] “Corrosion: Galvanic Corrosion.” The Stainless Steel Information Center, www.ssina.com/corrosion/galvanic.html.

Appendix A

Survey: Tennis Ball Hopper Questionnaire

Questions:

1. On a scale from 1 (not important) to 5 (extremely important), please rate each of these factors based on to their relations tennis ball hoppers.

- Light Weight
- Durability
- Mobile (to and from the car)
- Inexpensive
- Easy to Use
- Comfort
- Adjustable

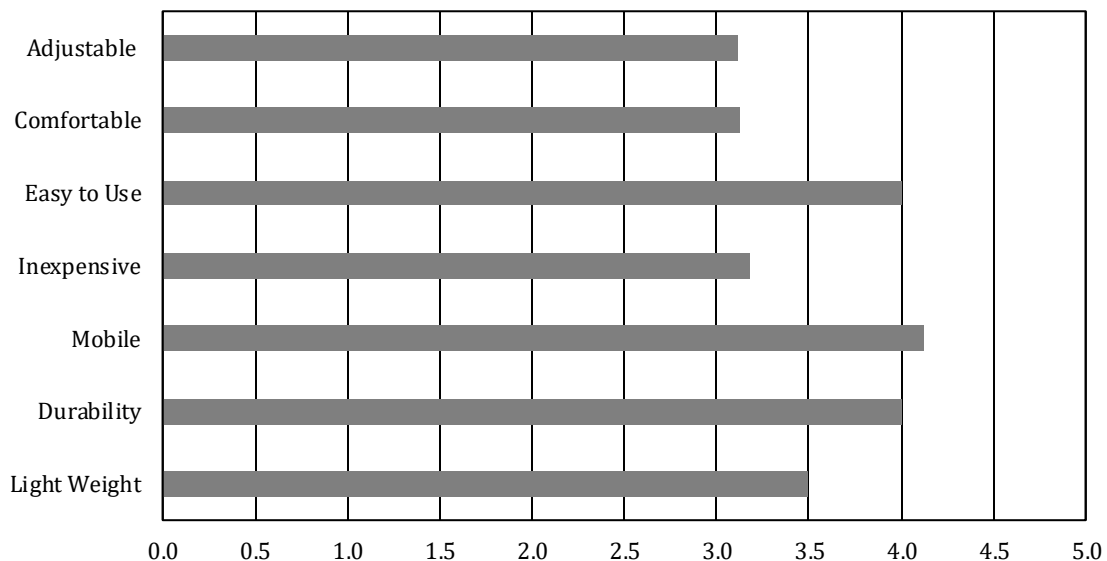
2. How many balls would you want a tennis ball hopper to carry?

3. What are some issues that you have with current tennis ball hoppers?

4. What are some features that you like about a tennis ball hopper that you have used or some features that you wish were present on a tennis ball hopper? Please describe the hopper used if applicable.

Results:

1. Chart A.1. Average responses of 17 tennis players from Cal Poly Tennis Club.



2. Average quantity of balls required for the hopper: 75

3. Common Issues:

- Easily Broken
- Heavy
- Flimsy
- Hard to transport
- Bulky

4. Features you like/wish you had:

- Lightweight
- Greater Stability
- Store Tennis Balls when not in use
- Locking Handles
- Convert from stand to hopper
- Adjustable handle
- Wheels

List of Customer Wants/Needs

- Wants it to carry 36-48 tennis balls
- Wants it to weigh 6-10 lbs
- Wants it to be purely mechanical
- Wants it to be easy enough for a 5-year old to operate
- Wants it to be mobile (Bring to and from court)
- Wants it to cost \$100-200
- Wants it to be durable

Different Tennis Ball Hopper Designs

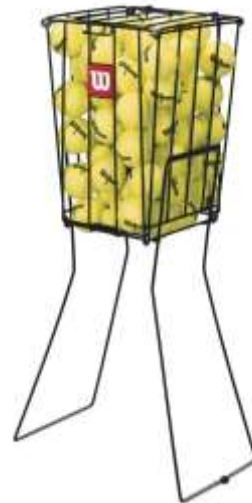


Figure A.1. Wilson Tennis Ball Hopper - \$30

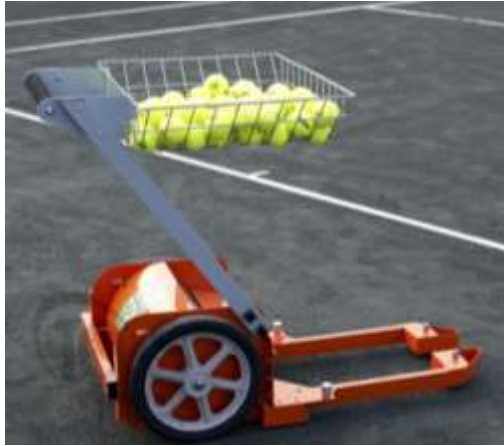


Figure A.2. Har-Tru Ball Mower - \$500



Figure A.3. Tennis Ball Roller Mower and Hopper - \$180



Figure A.4. Kollektaball CS60 - \$170



Figure A.5. Multimower - \$350



Figure A.6. Rapid Ball Boy - \$1500 (not available)



Figure A.7. Hill Hopper - \$2200



Figure A.8. Tomohopper - \$350



Figure A.9. Brad Tennis Ball Retriever - \$225

Appendix B

QFD: House of Quality

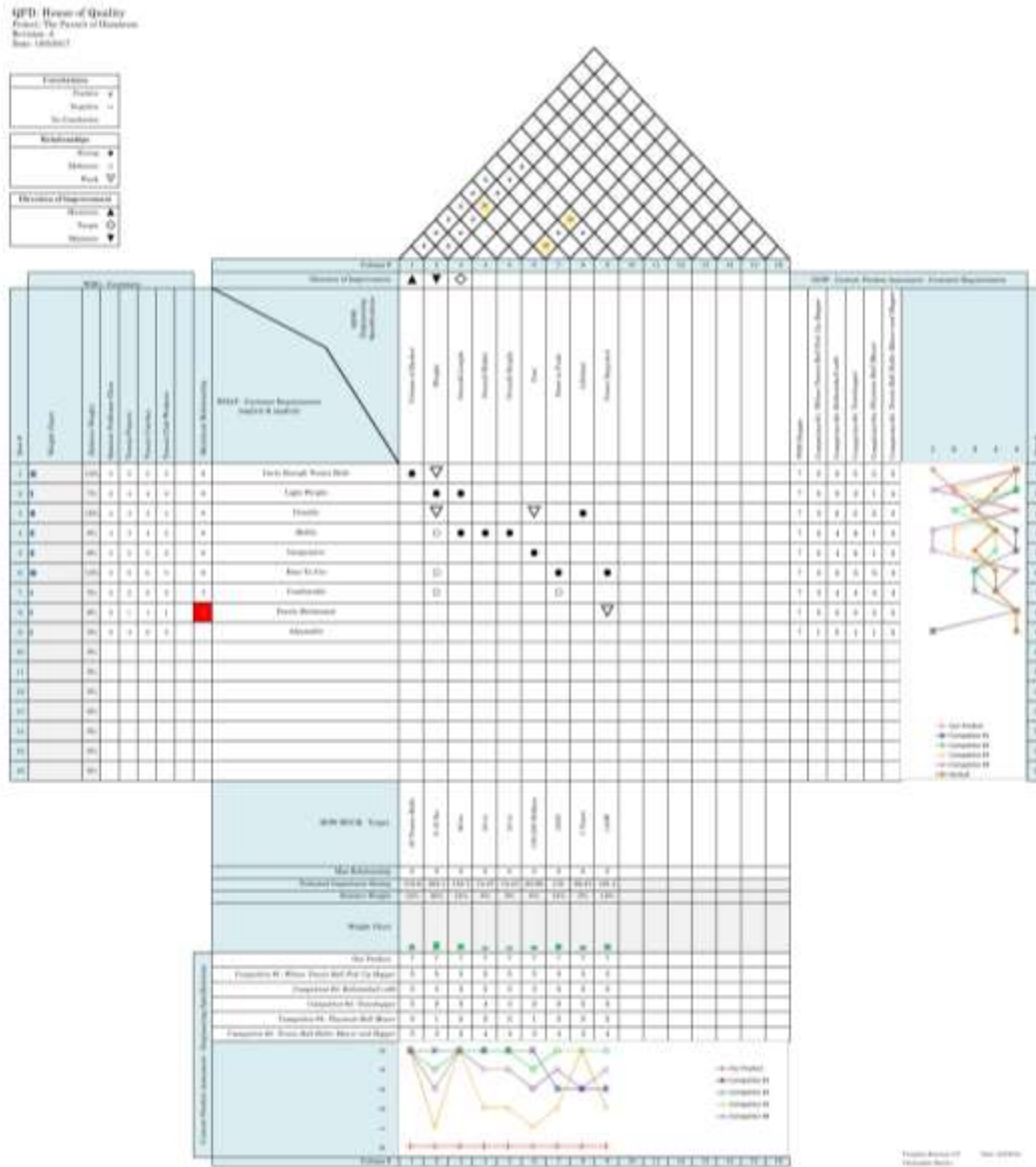


Figure B.1. Full QFD

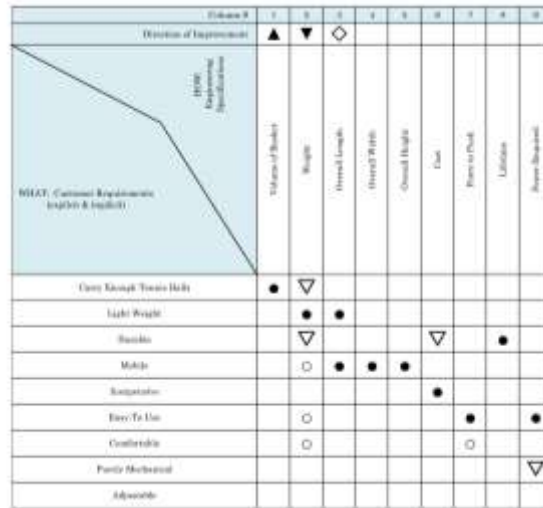


Figure B.2. How vs. What Section

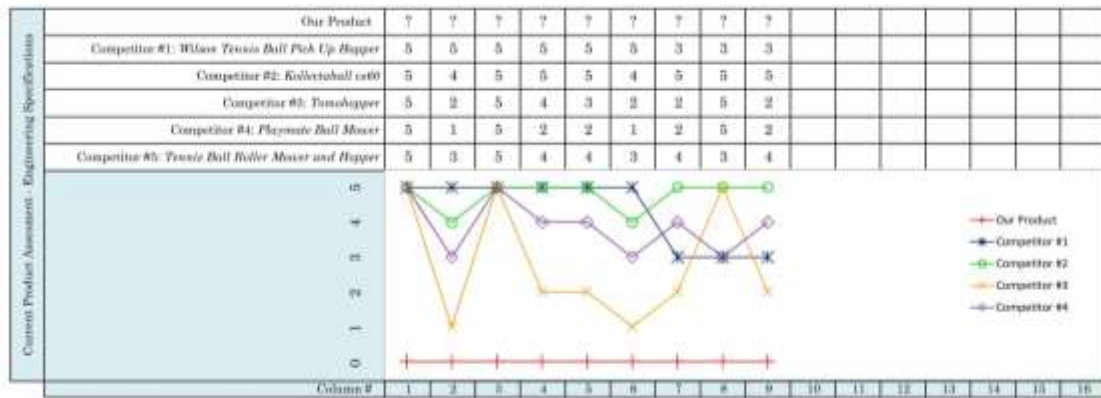


Figure B.3. Now vs. What Section

Appendix C

Ideation Session Notes and Decision Matrices

Ideation Session #1 – Picking up Tennis Balls

- Process - Brainwriting
- Results
 - Pick up tennis balls with Velcro belt
 - Use concentric circles, rotating outer circle stationary inner circle
 - Use stored energy from pushing to pick up balls
 - Suck up balls with vacuum power
 - Slide balls one at a time up tube
 - Balls roll up a helical coil when picked up
 - Belt driven mechanism
 - Slotted paddlewheel picks up balls
 - Use brushes to pick up balls
 - Lever brings up basket to usable height
 - Swiveling vacuum head

Ideation Session #2 – Storing Tennis Balls

- Process – Brainwriting
- Results
 - Wire metal cage
 - Plastic/canvas bag
 - Plastic Tupperware-like container
 - Store in tube
 - Store in helix
 - Store on the ground
 - Store in the wheels
 - Collect and store in a net
 - Pressurized basket
 - Slotted box attached to mechanism
 - Container with spring loaded bottom, balls always at same height

Ideation Session #3 – Raising Tennis Balls

- Process – Sticky notes
- Results



Figure C.1. Ideation session #3 results.

Ideation Session #4 – Transporting Tennis Balls

- Process – Sticky notes
- Results



Figure C.2. Ideation session #4 results.

Table C.1. Pugh Matrix focused on the function of gathering tennis balls

	Paddlewheel	Velcro Wheel	Wide Arms	Wheels Gather Balls	Tomohopper
Concept				- Slots for tennis balls 	
Criteria					
Leightweight	+	+	S	+	D
Durable	+	+	S	S	
Mobile	+	+	S	+	A
Inexpensive	+	+	+	+	
Easy to Use	-	-	S	S	T
Comfortable	-	-	S	-	
Adjustable	-	-	S	S	U
Sum(+)	4	4	1	3	
Sum(-)	3	3	0	3	M
Sum(S)	0	0	6	1	

Table C.2. Pugh Matrix showing the functions of transporting tennis balls to and from the court









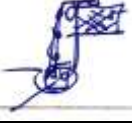





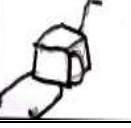
	Telescopic Arms	Frame as Dolley	Basket Lid	Detachable Basket	Collapsible	Backpack carry	Retractable handle	Tomohopper
Concept								
Criteria								
Lightweight	+	+	+	S	S	+	S	D
Durable	+	-	+	S	S	+	S	
Mobile	+	+	-	S	+	+	S	A
Inexpensive	-	-	-	S	S	-	S	
Easy to Use	-	+	+	+	+	+	S	T
Comfortable	S	+	S	S	+	-	S	
Adjustable	+	+	-	+	+	+	+	U
Sum(+)	4	5	3	2	4	5	1	
Sum(-)	2	2	3	0	0	2	0	M
Sum(S)	1	0	1	5	3	0	6	

Table C.3. Pugh Matrix showing the function of raising tennis balls

	Belt System	Raising Basket	Scissor Basket	Spring Loading	Wheel Launch	Wheel Raise	Tomohopper
Concept							
Criteria							
Adjustable	S	+	S	S	+	+	D
Comfortable	+	+	S	+	+	-	
Easy to Use	+	+	S	-	+	S	A
Inexpensive	-	+	-	-	+	+	
Mobile	+	-	+	-	+	+	T
Durable	-	+	+	+	+	+	
Lightweight	+	+	+	-	S	S	U
Sum(+)	4	6	3	2	6	4	
Sum(-)	2	1	1	4	0	1	M
Sum(S)	1	0	4	1	1	2	





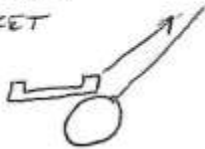
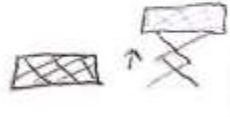



GATHERING	Paddlewheel 	Wide-Arms 	Wheel Roller 
RAISING	Belt Drive 	RAISING BASKET 	Scissor Basket 
TRANSPORT	Dolly 	Basket w/ lid 	Detachable Basket 

Figure C.3. A morphological matrix was created for the three most critical functions: transporting, gathering, and raising tennis balls

Table C.4. Five ideas created from the morphological matrix

Idea 1	Scissor basket, friction roller, basket lid
Idea 2	Wide arms, mower, raising basket, frame as dolly
Idea 3	Belt, detachable basket, wide arms
Idea 4	Friction roller, raising basket, detachable basket, dolly
Idea 5	Scissor basket, friction roller, dolly

Table C.5. Weighted Decision Matrix showing the specifications for the final product and the total weights of each idea

Factors	Lightweight	Durable	Mobile	Inexpensive	Easy to Use	Comfortable	Adjustable	Total
Weight	3	5	5	3	4	4	3	
Idea 1	9	25	15	6	15	12	15	97
Idea 2	9	20	20	9	15	20	15	108
Idea 3	9	20	20	6	20	20	15	110
Idea 4	9	20	20	9	15	20	15	108
Idea 5	9	20	20	9	15	20	15	108

Appendix D

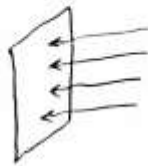
Preliminary Analyses

WEIGHT OF ONE TENNIS BALL
2 to 2 1/4 oz \Rightarrow 0.125 to 0.1289 lb
MAX WEIGHT OF 76 TENNIS BALLS 9.797 lb, CALL IT 10 lb
ADD ANOTHER 5 lb FOR BASKET

LIFTING FORCE = 15 lb

Figure D.1. Analysis for force required to lift basket.

WIND LOADING



WIND PRESSURE

$$P = 0.00256 \cdot V^4$$

① 100 mph

$$P = 0.00256 \cdot (100)^4$$

$$P = 25.6 \text{ psf}$$

$$F = P \cdot A$$

$$A = 1.5 \text{ ft} \times 3 \text{ ft} \\ = 4.5 \text{ ft}^2$$

$$F = 25.6 \text{ psf} (4.5 \text{ ft}^2)$$

$$\boxed{F = 115.2 \text{ lbs}} \quad !!!$$

② $V = 60 \text{ mph}$

$$P = 0.00256 (60)^4$$

$$= 9.216 \text{ psf}$$

$$F = P \cdot A$$

$$= (9.216 \text{ psf}) (4.5 \text{ ft}^2)$$

$$\boxed{F = 41.5 \text{ lb}}$$

WIND FORCE PRETTY HIGH.
WHEEL LOCKS MUST BE STRONG

Figure D.2. Analysis for wind loading.

VOLUME OF TENNIS BALLS (BIN)

$$N_b = \frac{V_{box}}{V_{ball}} \times \text{packing density}$$

$$V_{box} = \frac{(\# \text{ balls}) V_{ball}}{\text{packing density}}$$

$$\# \text{ balls} = 72$$

$$V_{ball} = \frac{\pi d^3}{4} = \frac{\pi (2.7 \text{ in})^3}{4} = 5.73 \text{ in}^3$$

$$\text{packing density} = \frac{\pi}{3\sqrt{2}}$$

$$V_{box} = 556.7 \text{ in}^3$$

$$= 0.322 \text{ ft}^3$$

Figure D.3. Analysis for bin volume.

Appendix E

Concept Layout Drawings

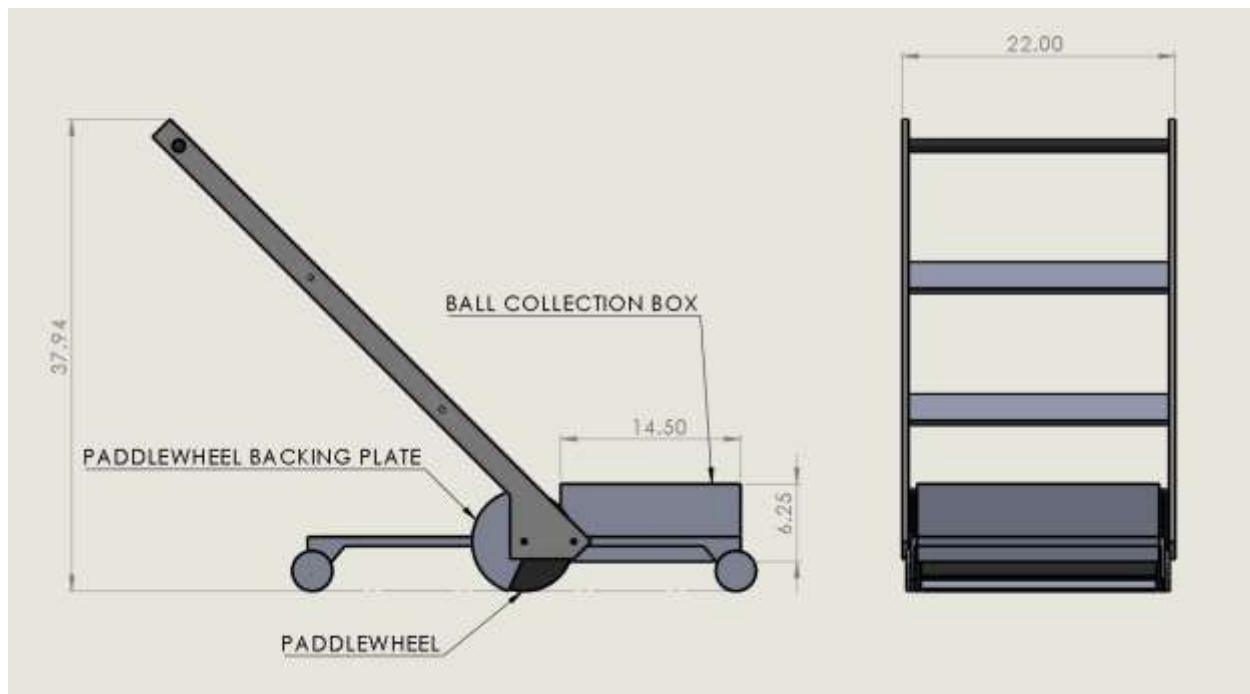


Figure E.1. Design Choice 1: this design uses a paddlewheel to pick up the balls and then deposits them into the collection box. The box is then able to raise along the slide rails for a higher final position.

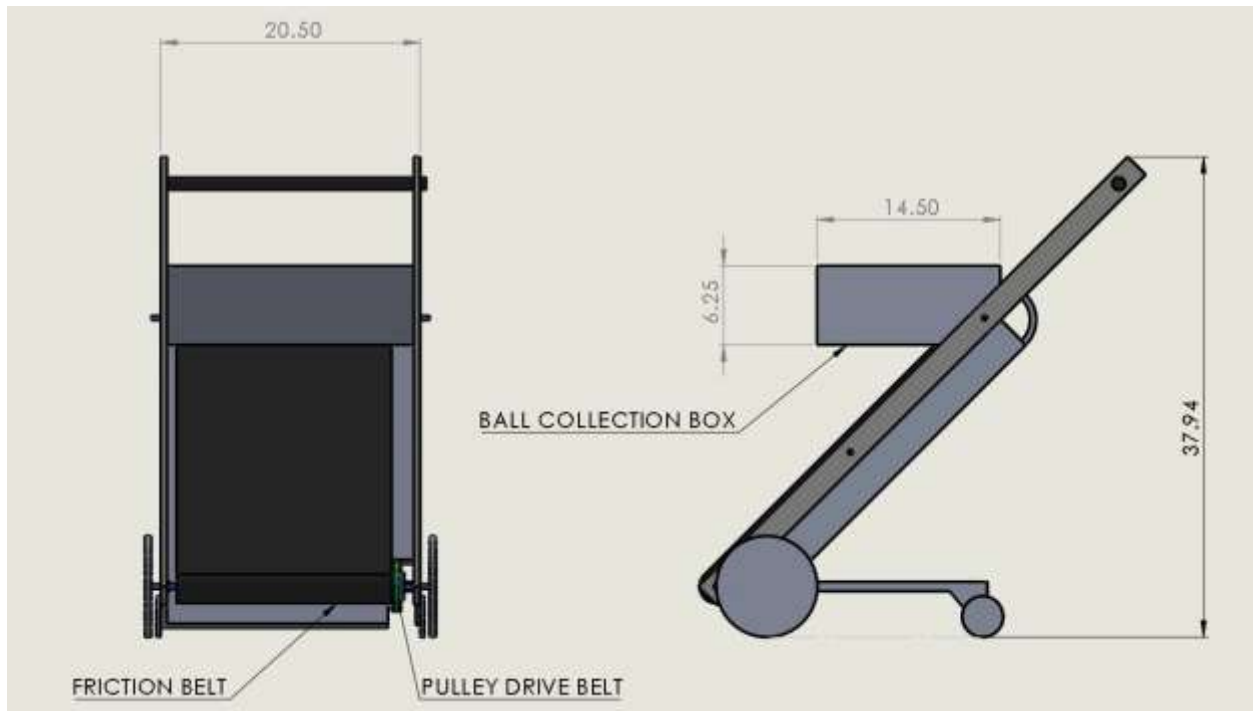


Figure E.2. Design Choice 2: this design utilizes a large friction belt to bring the balls from the ground to a stationary collection box.

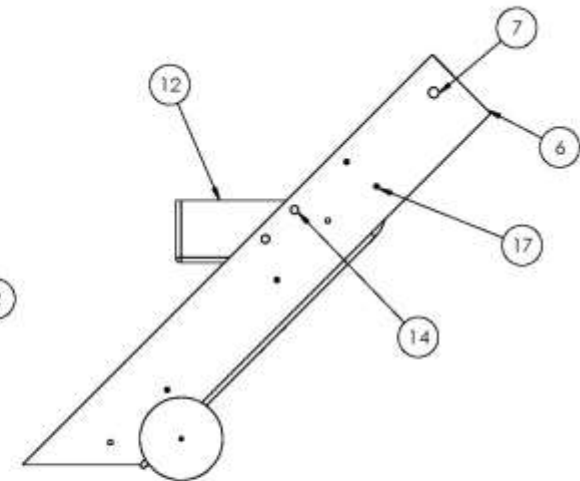
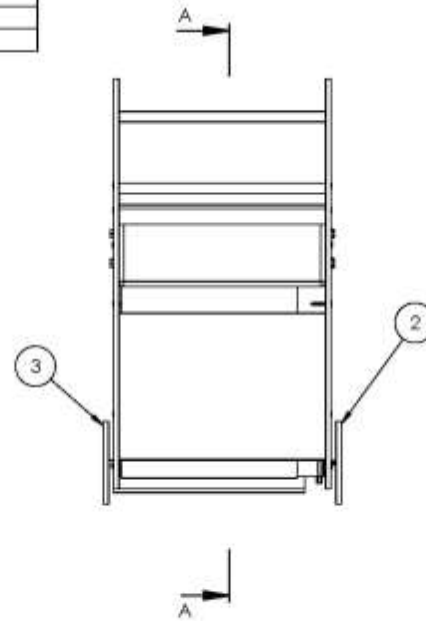
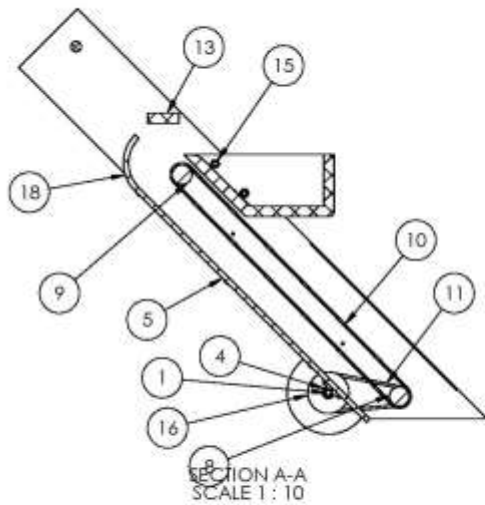
Appendix F

Complete Drawing Package for Belt Drive Model

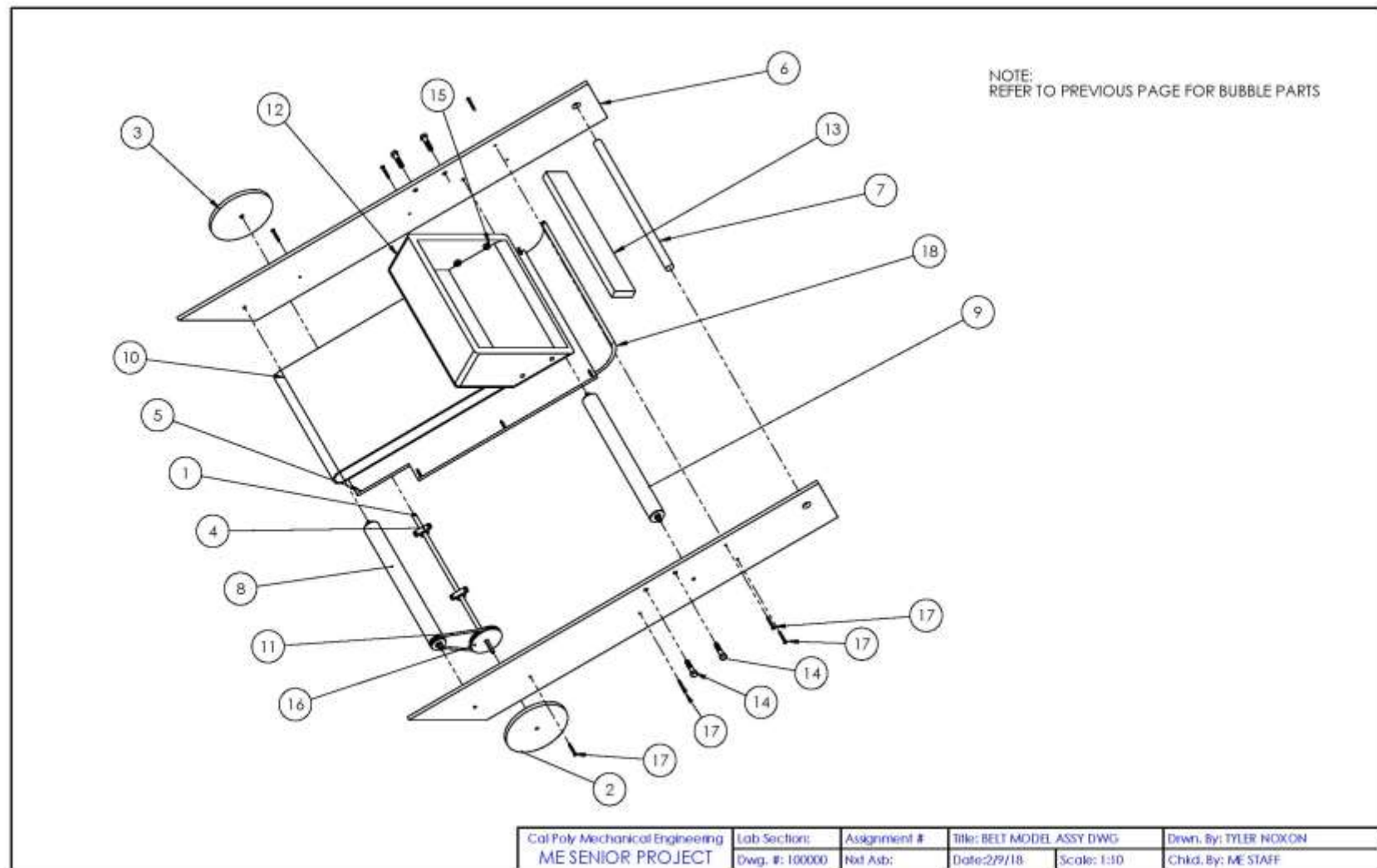
	Indented Bill of Material (BOM)											
	Tennis Ball Hopper Belt Model											
Assy Level	Part Number	Description				Matl	P/M	Vendor	Vendor Part #	Qty	Cost	Ttl Cost
		Lvl0	Lvl1	Lvl2	Lvl3							
0	100000	Belt Model Assy				---	---	---	---	1	---	---
1	101000	Belt/Frame Assy				---	---	---	---	1	---	---
2	102000			Back Plate		HDPE	M	---	---	1	\$ 40.00	\$ 40.00
2	102001			Side Plate		HDPE	M	---	---	1	\$ 20.00	\$ 20.00
2	102002			Bottom Conveyor Roller		Galvanized Steel	P	McMaster-Carr	2277T56	1	\$ 12.74	\$ 12.74
2	102003			Top Conveyor Roller		Galvanized Steel	P	McMaster-Carr	2277T56	1	\$ 12.74	\$ 12.74
2	102004			Lift Belt		Oil-Resistant Neoprene	P	McMaster-Carr	5751K301	1	\$ 51.28	\$ 51.28
2	102018			Alligator Lacing		Stainless Steel	P	McMaster-Carr	6116K102	1	\$ 98.67	\$ 98.67
2	102005			Mid Plate		HDPE	M	---	---	1	\$ 10.00	\$ 10.00
2	102006			Push Shaft		HDPE	P	---	---	1	\$ 4.00	\$ 4.00
2	102007			Drive Belt		Neoprene Rubber	P	McMaster-Carr	8060K199	1	\$ 3.98	\$ 3.98
2	102019			Ramp		PVC Plastic	M	---	---	1	\$ 2.00	\$ 2.00
2	102008			Bumper		HDPE	M	---	---	1	\$ 4.00	\$ 4.00
2	102009			Side Plate		HDPE	M	---	---	1	\$ 20.00	\$ 20.00
1	101001	Drive Assy				---	---	---	---	1	---	---
2	102010			Bearing Mounts		Stainless Steel	P	McMaster-Carr	5912K400	2	\$ 11.11	\$ 22.22
2	102011			Drive Shaft		Stainless Steel	M	---	---	1	\$ 5.00	\$ 5.00
2	102018			Key		Stainless Steel	P	McMaster-Carr	98493A100	1	\$ 3.44	\$ 3.44
2	102012			Belt Pulley		UHMW Plastic	P	McMaster-Carr	6284K560	1	\$ 20.75	\$ 20.75
2	102013			Drive Wheel		HDPE	M	---	---	2	\$ 2.00	\$ 4.00
1	101002	Bin Assy				---	---	---	---	1	---	---
2	102014			Bin		Plastic	P	Target	---	1	\$ 10.00	\$ 10.00
2	102015			Bolt		Stainless Steel	P	McMaster-Carr	92198A437	4	\$ 5.44	\$ 21.76
2	102016			Hex Nut		Stainless Steel	P	McMaster-Carr	91847A525	4	\$ 6.36	\$ 25.44
2	102017			Lock Nut		Stainless Steel	P	McMaster-Carr	91831A140	4	\$ 6.86	\$ 27.44
1	101003	Screws				Stainless Steel	P	McMaster-Carr	92325A317	12	\$ 13.41	\$ 13.41
1	101004	Safety Cover				Polycarbonate	P	---	---	1	\$ 5.00	\$ 5.00
									Total Parts	49	@	\$ 437.87

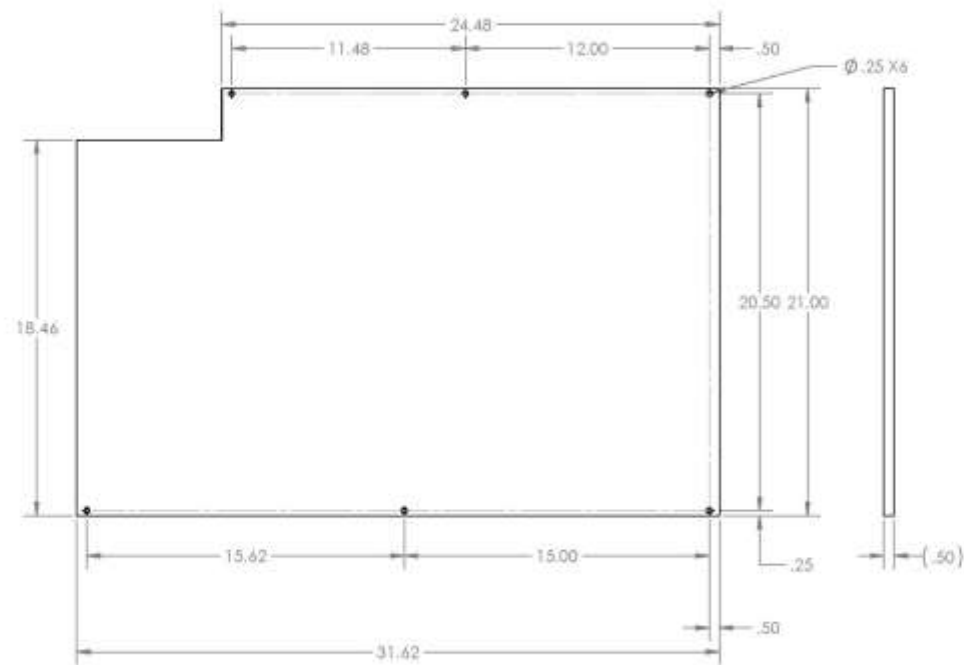
Figure F.1. Indented Bill of Materials for Belt Drive Mechanism

ITEM NO.	PART NUMBER	DESCRIPTION	Default/QTY.
1	102011	Drive Shaft	1
2	102013	Drive Wheel 1	1
3	102014	Drive Wheel 2	1
4	102010	Bearing Mount	2
5	102000	Back Plate	1
6	102001	Side Plate	2
7	102006	Push Shaft	1
8	102002	Bottom Conveyor Roller	1
9	102003	Top Conveyor Roller	1
10	102004	Lift Belt	1
11	102007	Drive Belt	1
12	102015	Bin	1
13	102008	Bumper	1
14	102016	1/2" Bolt	4
15	102017	1/2" Hex Nut	4
16	102012	Belt Pulley	1
17	101001	1/4" Screw	14
18	102019	Ramp	1
19	102020	Safety Cover	1



Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: BELT MODEL ASSY DWG	Drawn By: GEORGE DEGRANDIS
ME SENIOR PROJECT	Dwg. #: 100000	Nxt Ass:	Date: 1/30/18	Scale: 1:10
				Chkd. By: ME STAFF



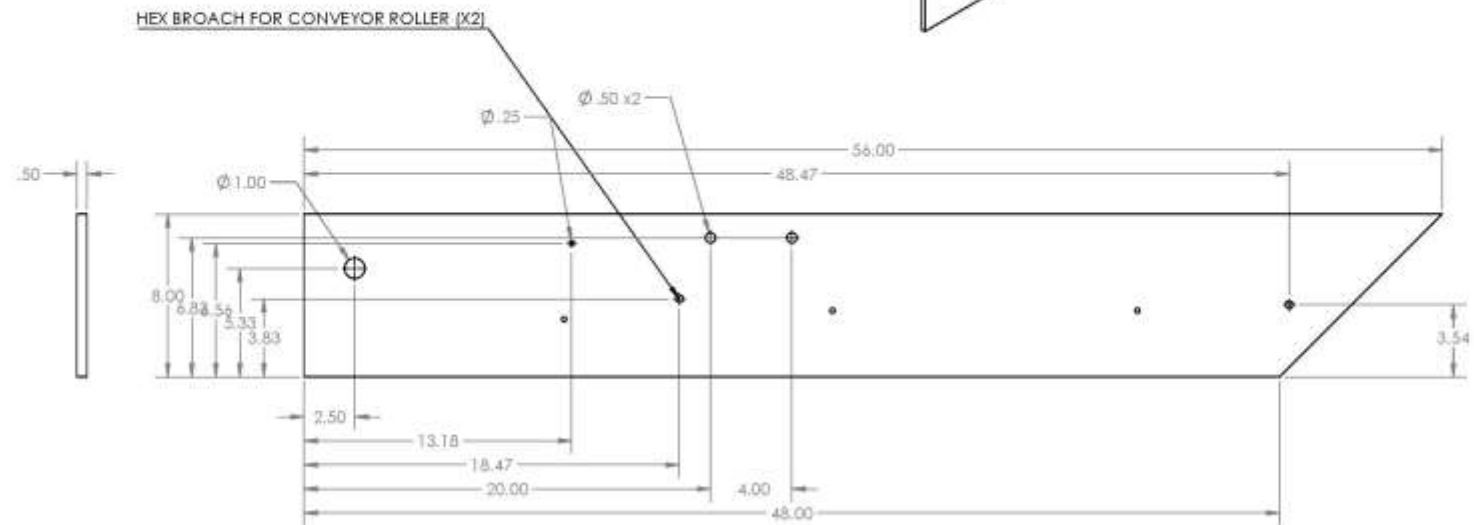


- NOTES:
- 1.) ALL DIMENSIONS IN INCHES
 - 2.) MATERIAL: HDPE PLASTIC
 - 3.) ALL TOLERANCES ± 0.01

Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: BACK PLATE	Drawn By: GEORGE DEGRANDE
ME SENIOR PROJECT	Dwg. #: 102000	Ntd Asb:	Date: 2/9/2018	Scale: 1:5
				Chkd. By: ME STAFF

- NOTES:
 1. ALL DIMENSIONS IN INCHES
 2. MAT'L: HDPE PLASTIC
 3. TOLERANCES
 X.XX \pm 0.01

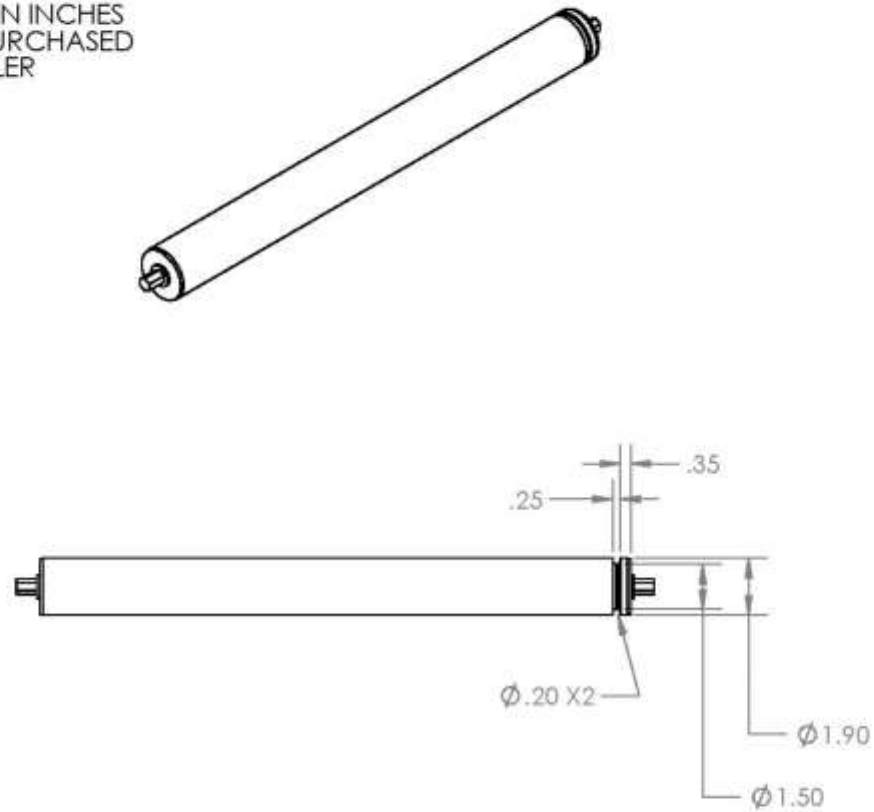
ISO SCALE - 1:10



Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: SIDE PLATE	Drawn By: GEORGE DEGRANDE
ME SENIOR PROJECT	Dwg. #: 102001	Ntd Asb:	Date: 1/00/18	Scale: 1:5
				Chkd. By: ME STAFF

NOTES

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MODIFYING OF PURCHASED CONVEYOR ROLLER
- 3.) ALL DIMS ± 0.01



Cal Poly Mechanical Engineering
ME SENIOR PROJECT

Lab Section:
Dwg. #: 102002

Assignment #
Nxt Asb:

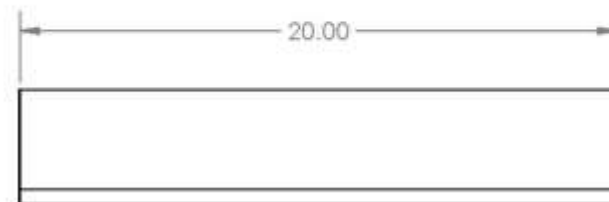
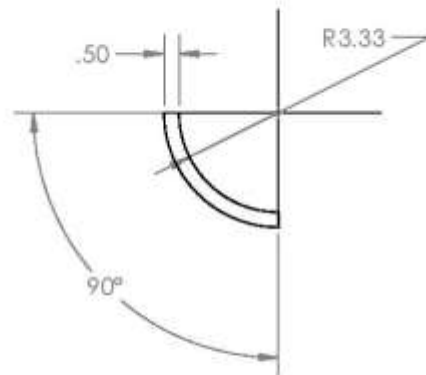
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Date: 1/30/18

Scale: 1:5

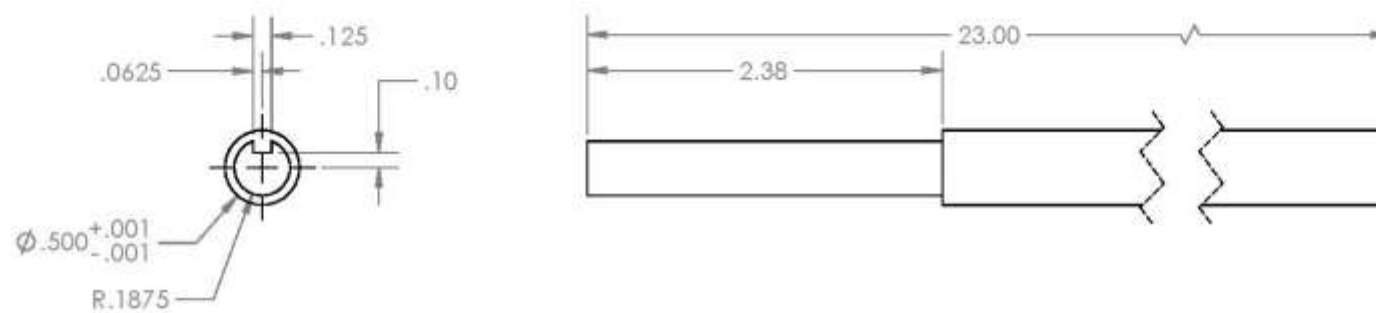
Drwn. By: GEORGE DEGRANDIS
Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) PART WILL BE CUT FROM PVC
- 3.) ALL DIMS ± 0.01
- 4.) ANGLES $\pm 1^\circ$

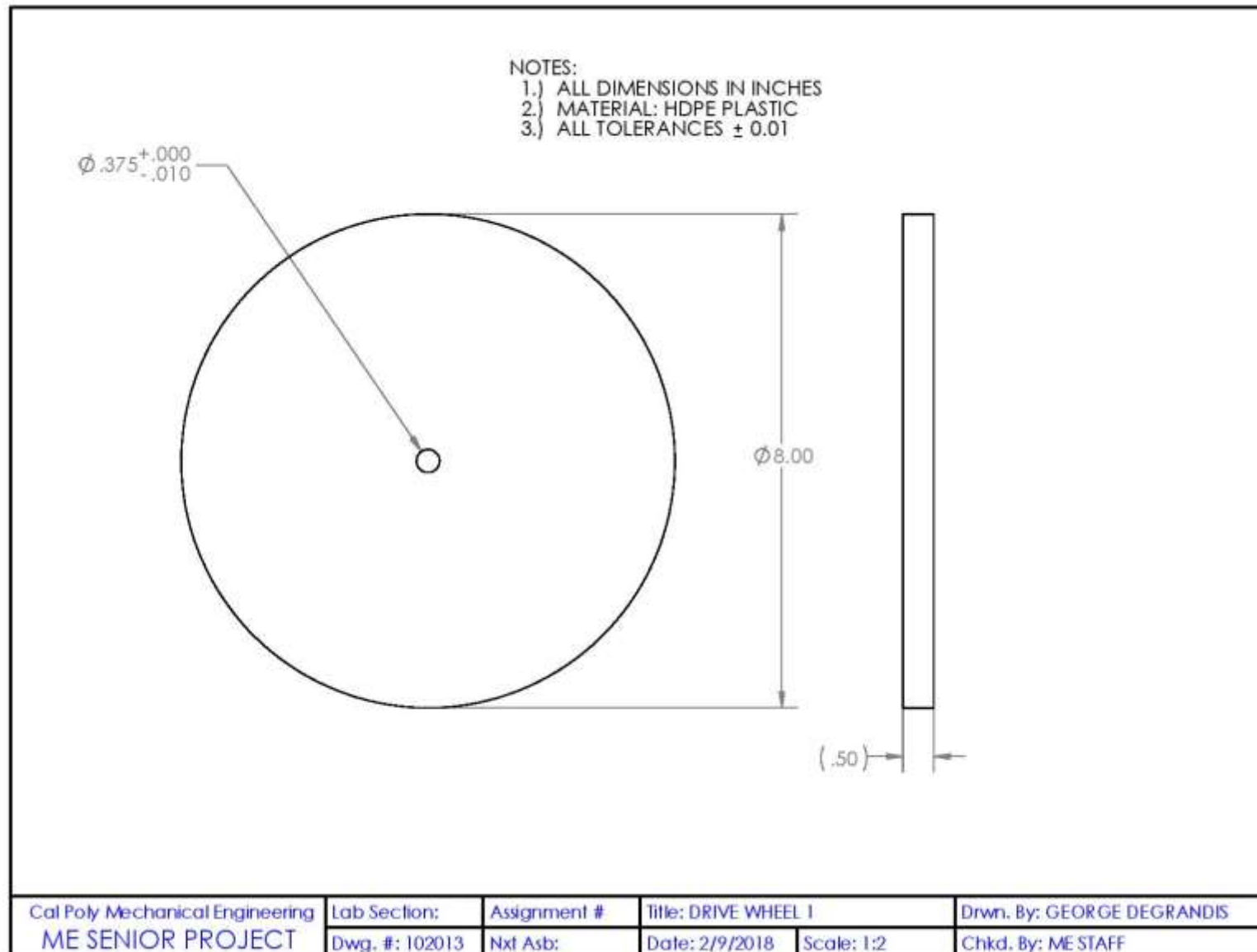


Cal Poly Mechanical Engineering ME SENIOR PROJECT	Lab Section:	Assignment #:	Title: RAMP		Drwn. By: GEORGE DEGRANDIS
	Dwg. #: 102019	Nxt Asb:	Date: 1/30/18	Scale: 1:5	Chkd. By: ME STAFF



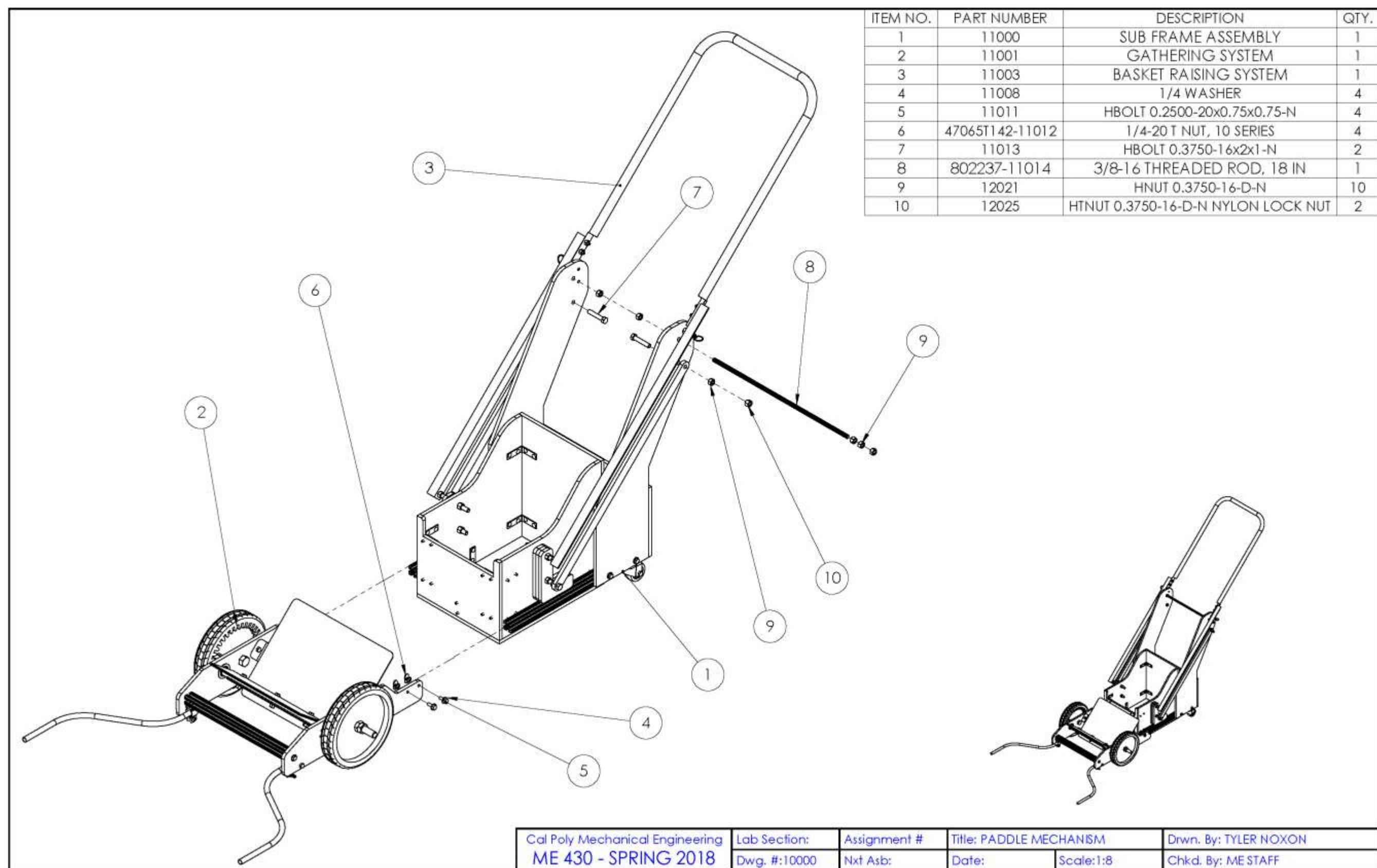
- NOTES:
- 1.) ALL DIMENSIONS IN INCHES
 - 2.) MATERIAL: STAINLESS STEEL
 - 3.) USE LATHE TO TURN, MILL TO CUT KEYWAY
 - 4.) $X.XX \pm 0.01$

Cal Poly Mechanical Engineering ME SENIOR PROJECT	Lab Section:	Assignment #	Title: DRIVE SHAFT		Drwn. By: GEORGE DEGRANDIS
	Dwg. #: 102011	Nxt Asb:	Date: 2/8/2018	Scale: 1:1	Chkd. By: ME STAFF

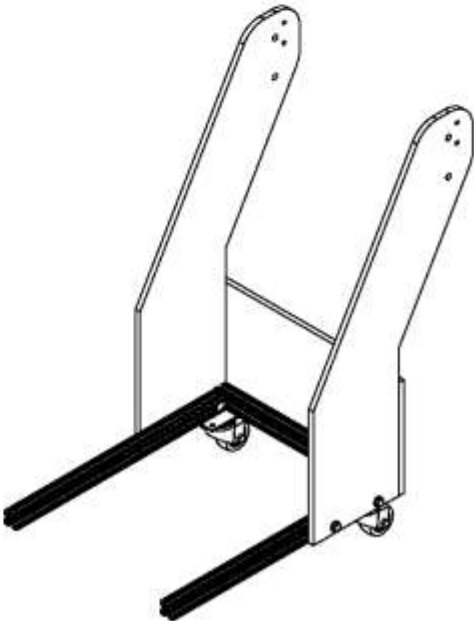
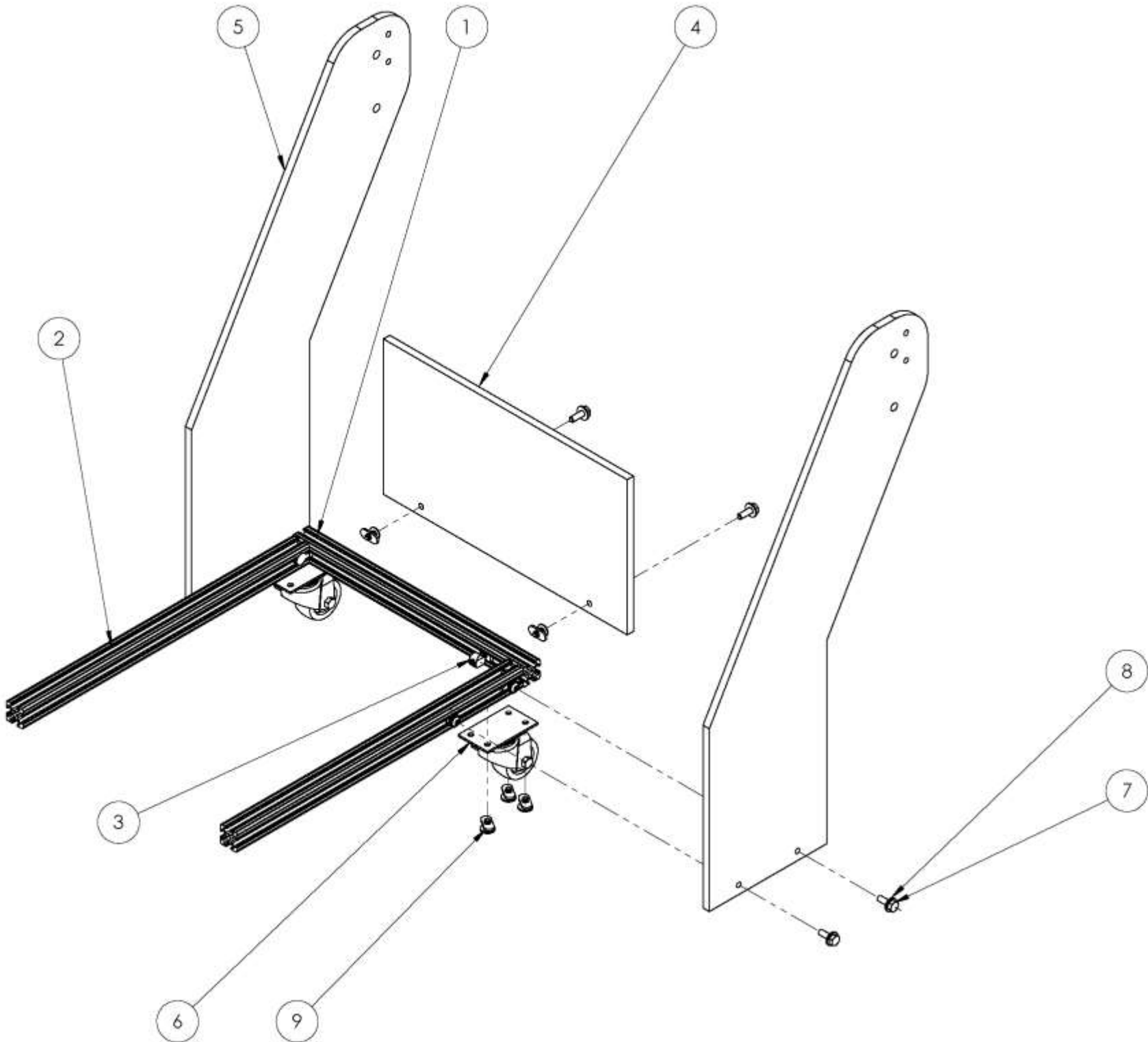


Complete Drawing Package for Paddlewheel Model

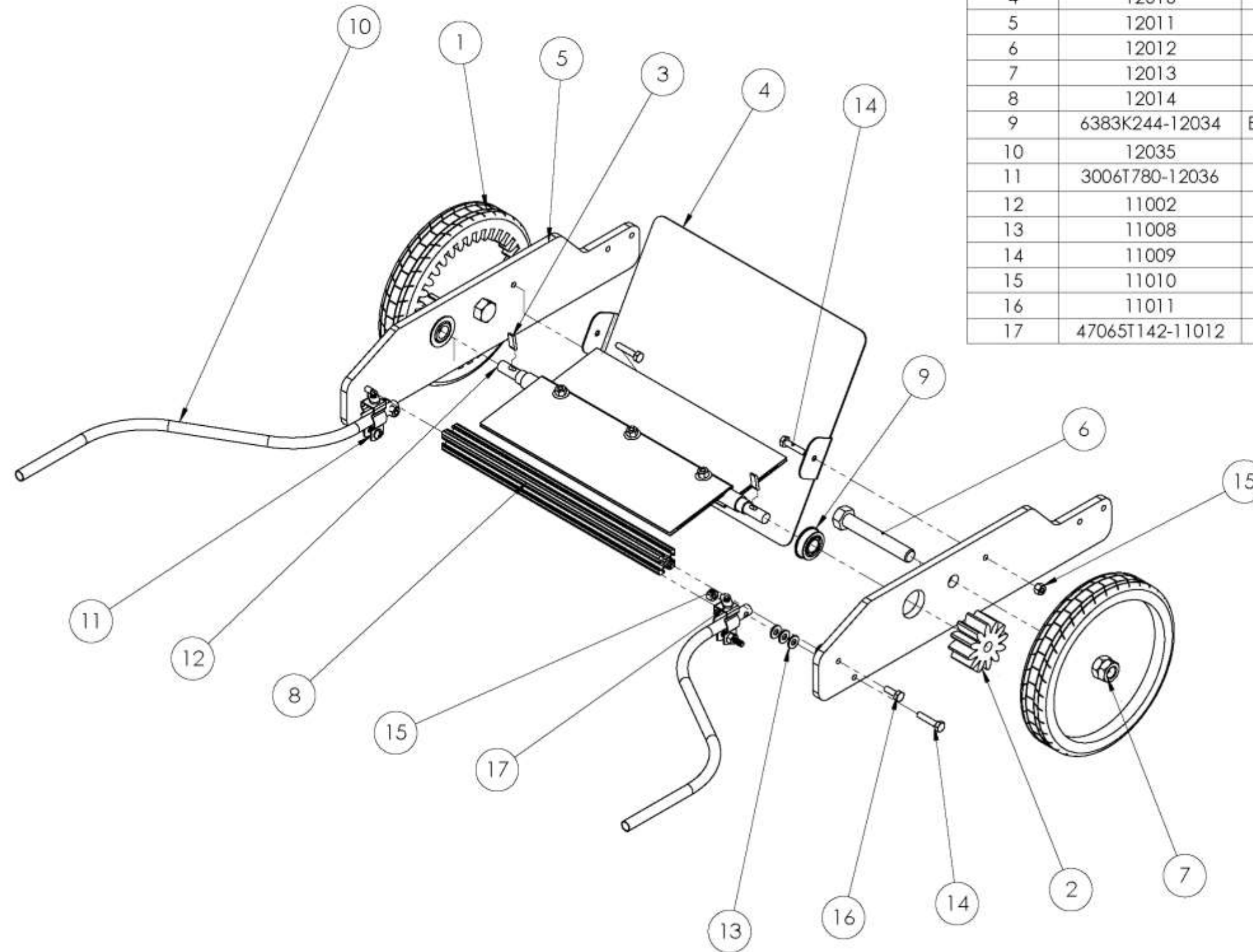
Indented Bill of Material (BOM)									
Paddle Mechanism									
Assy Level	Part Number	Description	Matl	Vendor	Qty	Cost	Ttl Cost		
		Lvl0 Lvl1 Lvl2 Lvl3							
0	10000	Paddle Assembly							
1	11000	Sub Frame Assembly					\$ 29.78		
2	12001	80/20 Rear Rail	Aluminum	Mcmaster	1	7	\$ 7.00		
2	12002	80/20 Cross Rail	Aluminum	Mcmaster	2	8	\$ 16.00		
2	47065T153-12003	80/20 Anchor 1"	Zinc	Mcmaster	2	3.39	\$ 6.78		
2	12004	body rear plate	HDPE	Polymersan	1		\$ -		
2	12005	body basket support	HDPE	Polymersan	2		\$ -		
2	2406T630-12006	castor wheels	rubber/steel	Mcmaster	2	2.99	\$ 5.98		
1	11001	Gather System					\$ 122.75		
2	10446-12007	Drive Wheel	plastic	searspartsdirect	2	12.6	\$ 25.20		
2	30737-1-12008	Pinion Gear*	plastic	searspartsdirect	2	7.5	\$ 15.00		
2	30316-12009	Ratchet Pawl	steel	searspartsdirect	2	4.08	\$ 8.16		
2	12010	ball ramp	steel	ace-miners	1	9.69	\$ 9.69		
2	12011	body drive support	HDPE	Polymersan	2		\$ -		
2	97178-12012	5/8-11 4" hex cap screw	zinc plated	home depot	2	1.97	\$ 3.94		
2	801786-12013	5/8-11 4" hex nut	zinc plated	home depot	4	0.35	\$ 1.40		
2	12014	FRONT FRAME PIECE	aluminum	mcmaster	1	7	\$ 7.00		
2	6383K241-12034	flange bearing .5 ID	steel	mcmaster	2	12.39	\$ 24.78		
2	12035	gathering arms	aluminum	mcmaster	2	13.46	\$ 26.92		
2	3006T780-12036	arm pipe hangers	steel	mcmaster	2	0.33	\$ 0.66		
1	11002	Paddle wheel assembly					\$ 12.18		
2	12015	Paddle wheel shaft	aluminum	mcmaster	1	5.77	\$ 5.77		
2	GE-34-12016	paddle fins	polycarbonate	home depot	2	2.245	\$ 4.49		
2	12017	paddle fin coating material	vinyl sheet	home depot	2	0.96	\$ 1.92		
1	11003	Basket Raising system					\$ 79.37		
2	12018	upper arm linkage left	Aluminum	home depot	1	9.97	\$ 9.97		
2	12019	upper arm linkage right	Aluminum	homedepot	1	9.97	\$ 9.97		
2	12020	lower arm linkages	HDPE	Polymersan	2		\$ -		
2	94819A049-12021	3/8-16 hex nut	zinc-plated	home depot (25)	1	2.7	\$ 2.70		
2	12022	3/8-16 bolts 4L	zinc plated	home depot	6	1.29	\$ 7.74		
2	802324-12023	3/8 washers	zinc plated	home depot	1	3.14	\$ 3.14		
2	12024	basket rail mount	HDPE	Polymersan			\$ -		
2	12025	3/8-16 nylon lock nut	zinc plated	home depot (10)	2	1.97	\$ 3.94		
2	4502759-12026	Handle Bar	steel tube	repairclinic.com	1	20.37	\$ 20.37		
2	8482A42-12027	Cable lock	brass	mcmaster	2	10.77	\$ 21.54		
1	11004	Basket Assembly					\$ 26.98		
2	12028	basket front	HDPE	Polymersan			\$ -		
2	12029	basket sides	HDPE	polymersan			\$ -		
2	12030	basket back and base	HDPE	polymersan			\$ -		
2	15267-12032	basket brackets 2 in	GALVANIZED	home depot (4)	4	4.68	\$ 18.72		
2	803031-12033	6-32 x .75l nuts and bolts	STAINLESS	home depot (8)	7	1.18	\$ 8.26		
		3/8 HDPE sheet 2' x4'	HDPE	Polymersan	2	53	\$ 106.00		
1	11008	1/4 washers	zinc plated	home depot	25	0.13	\$ 3.25		
1	11009	hex cap .25-20 -11L	zinc plated	home depot	16	0.12	\$ 1.92		
1	2991-11010	nylon hex nut 1/4-20	zinc plated	home depot (15)	1	4.93	\$ 4.93		
1	11011	1/4-20-.75L hexcap	zinc plated	home depot	16	0.11	\$ 1.76		
1	47065T142-11012	t-slot fasteners	steel	mcmaster(4)	4	2.3	\$ 9.20		
1	98957A133-11014	3/8-16 threaded rod 18in	zinc plated	home depot	1	2.87	\$ 2.87		
1	11013	3/8-16 hex bolt 2"	zinc plated	home depot	2	0.15	\$ 0.30		
*For left and right needed							TOTAL	\$ 401.29	



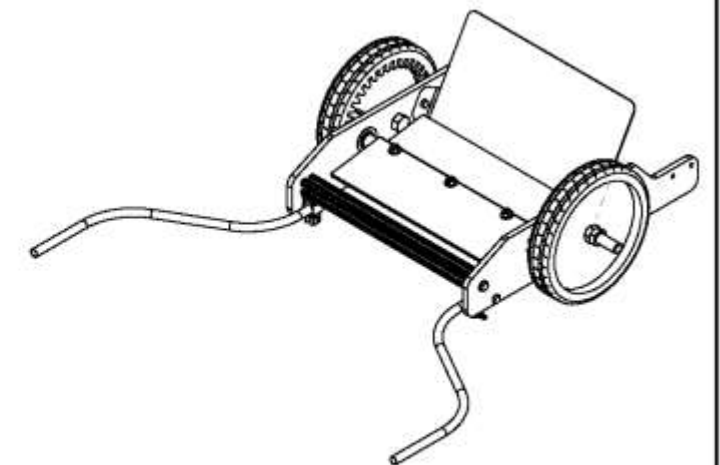
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	12001	80/20 REAR RAIL	1
2	12002	80/20 CROSS RAIL	2
3	47065T153-12003	80/20 ANCHOR, 10SERIES	2
4	12004	BODY REAR PLATE	1
5	12005	BODY BASKET SUPPORT	2
6	2406T630-12006	2" DIA MIGHTY-LITE CASTER	2
7	11011	HBOLT 0.2500-20x0.75x0.75-N	6
8	11008	1/4 WASHER	12
9	47065T142-11012	1/4-20 T NUT, 10 SERIES	12



Cal Poly Mechanical Engineering ME 430 - SPRING 2018	Lab Section:	Assignment #	Title: SUB FRAME ASSEMBLY	Drwn. By: TYLER NOXON	
	Dwg. #: 11000	Nxt Asb:	Date:	Scale: 1:5	Chkd. By: MESTAFF



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	532403111-12007	DRIVE WHEEL	2
2	30036-1-12008	PINION GEAR	2
3	12009	RATCHET PAWL	2
4	12010	BALL RAMP	1
5	12011	BODY DRIVE SUPPORT	2
6	12012	HBOLT 0.6250-11x4x1.5-N	2
7	12013	HJNUT 0.6250-11-D-N	4
8	12014	FRONT FRAME PIECE	1
9	6383K244-12034	Ball Bearing, Flanged, 1/2" Shaft, 1-3/8" Housing ID	2
10	12035	GATHERING ARMS	2
11	3006T780-12036	Threaded-Rod-Mount Clamping Hanger	2
12	11002	PADDLE WHEEL ASSEMBLY	1
13	11008	1/4 WASHER	8
14	11009	HBOLT 0.2500-20x1.25x0.75-N	4
15	11010	HTNUT 0.2500-20-D-NYLON LOCK NUT	4
16	11011	HBOLT 0.2500-20x0.75x0.75-N	2
17	47065T142-11012	1/4-20 T NUT, 10 SERIES	2



Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

Lab Section:
Dwg. #: 11001

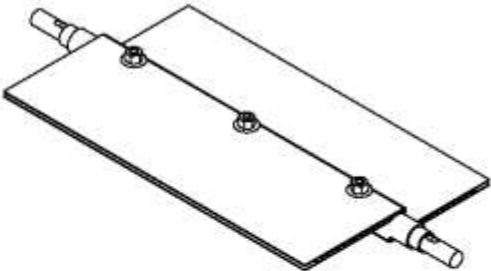
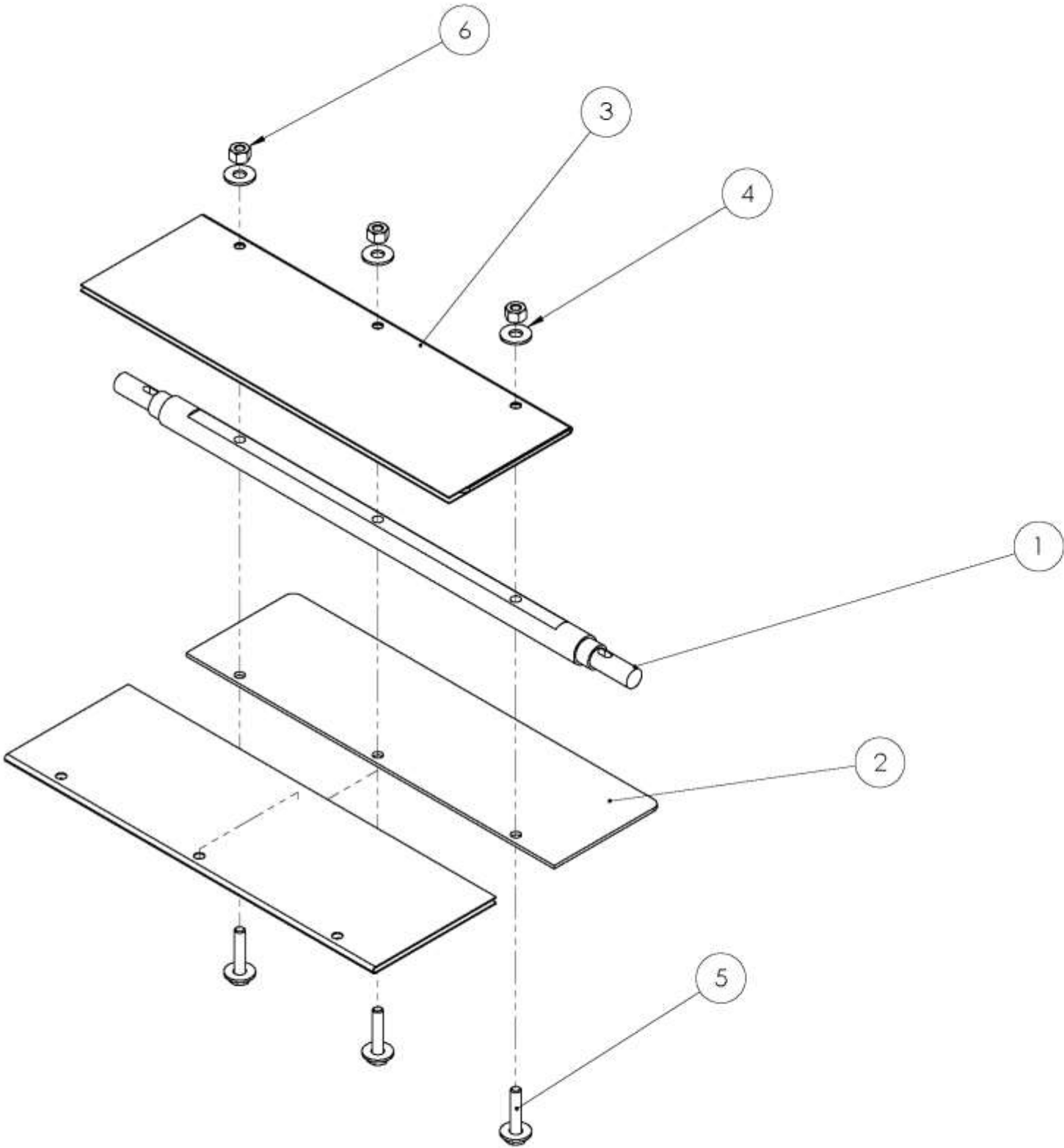
Assignment #
Nxt Asb:

Title: GATHERING SYSTEM
Date:

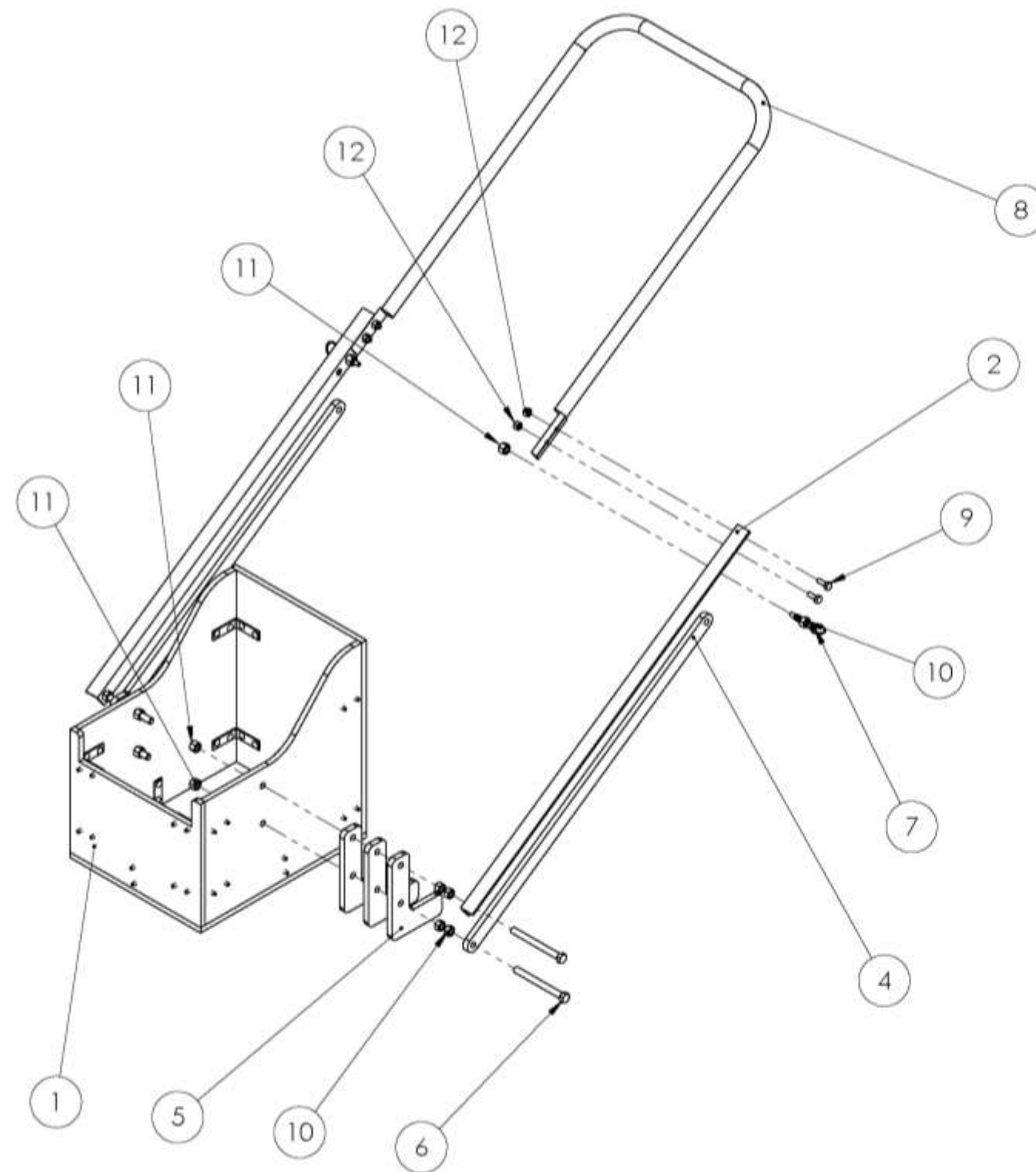
Scale: 1:5

Drwn. By: TYLER NOXON
Chkd. By: ME STAFF

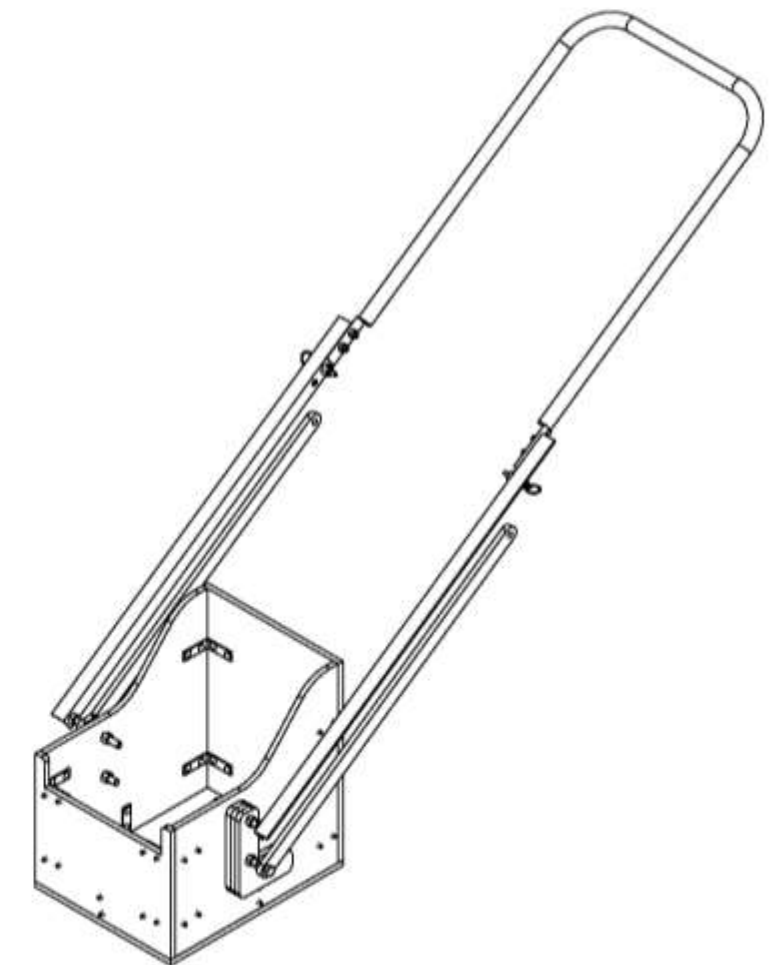
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	12015	DRIVE SHAFT	1
2	12016	PADDLE FIN	2
3	12017	PADDLE FIN COATING	2
4	11008	1/4 WASHER	6
5	11009	HBOLT 0.2500-20x1.25x0.75-N	3
6	11010	HTNUT 0.2500-20-D-NYLON LOCK NUT	3



Cal Poly Mechanical Engineering ME 430 - SPRING 2018	Lab Section:	Assignment #	Title: PADDLE WHEEL ASSEMBLY	Drwn. By: TYLER NOXON	
	Dwg. #:11002	Nxt Asb:	Date:	Scale: 1:3	Chkd. By: ME STAFF



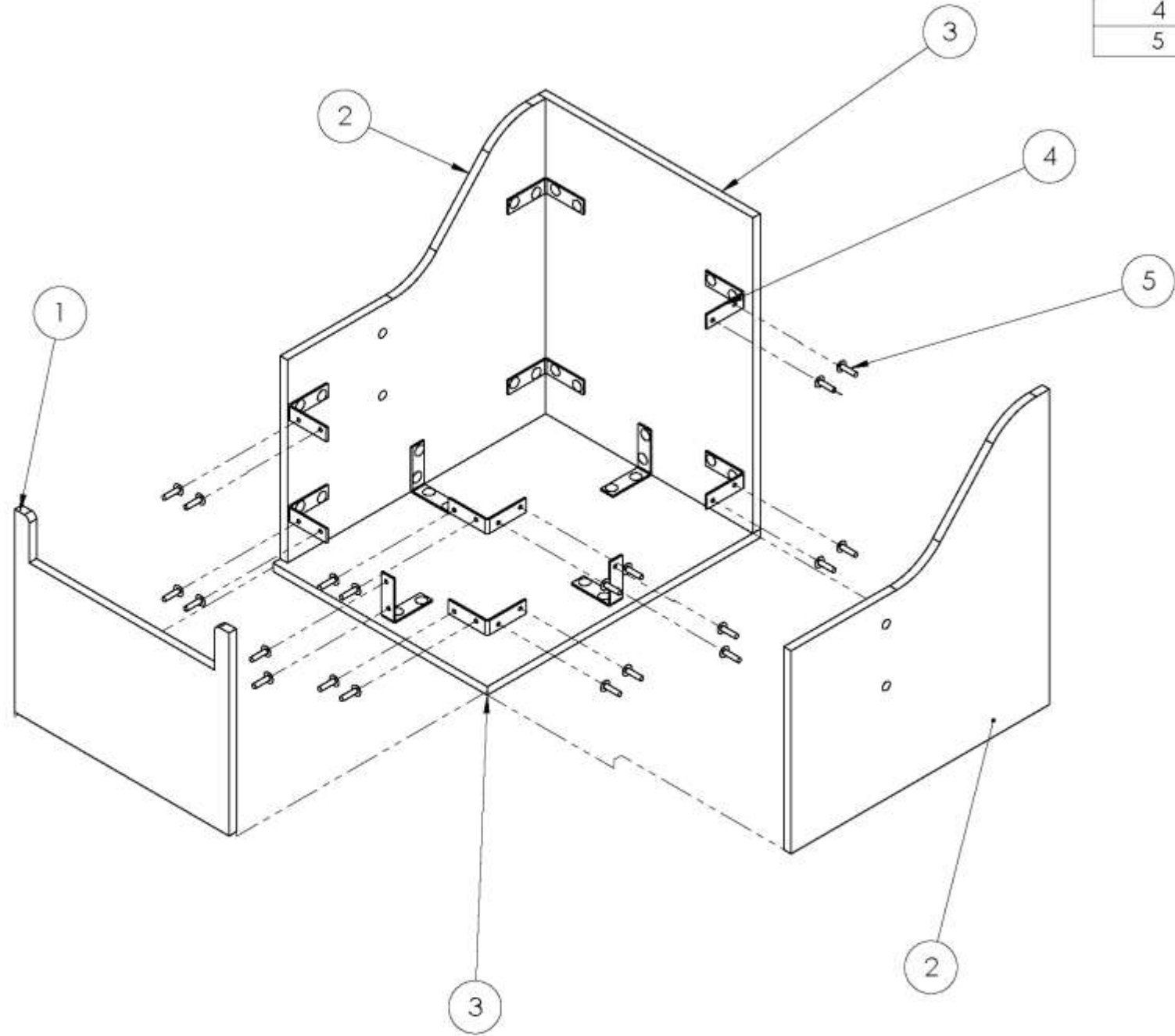
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	11004	BASKET ASSEMBLY	1
2	12018	UPPER LINK LEFT	1
3	12019	UPPER LINK RIGHT	1
4	12020	LOWER LINK	2
5	12024	BASKET RAIL MOUNT	6
6	12022	HBOLT 0.3750-16x4x1-N	4
7	8482A421-12027	Brass Pull-Ring Retractable Spring Plunger	2
8	4502759-12026	HANDLE BAR	1
9	11011	HBOLT 0.2500-20x0.75x0.75-N	4
10	12021	HNUT 0.3750-16-D-N	10
11	12025	HTNUT 0.3750-16-D-N NYLON LOCK NUT	6
12	11010	HTNUT 0.2500-20-D-NYLON LOCK NUT	4



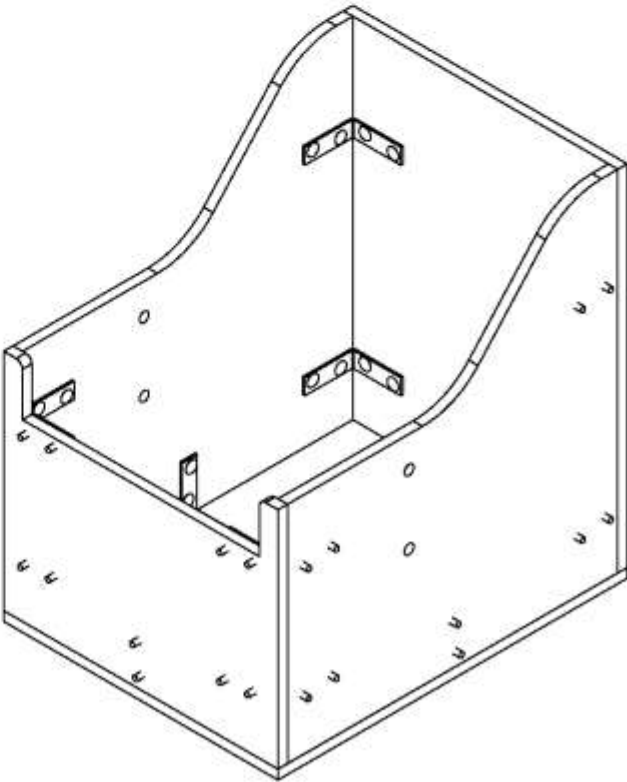
Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

Lab Section:	Assignment #	Title: BASKET RAISING SYSTEM	Drwn. By: TYLER NOXON
Dwg. #: 11003	Nxt Asb:	Date:	Scale:1:8 Chkd. By: MESTAFF

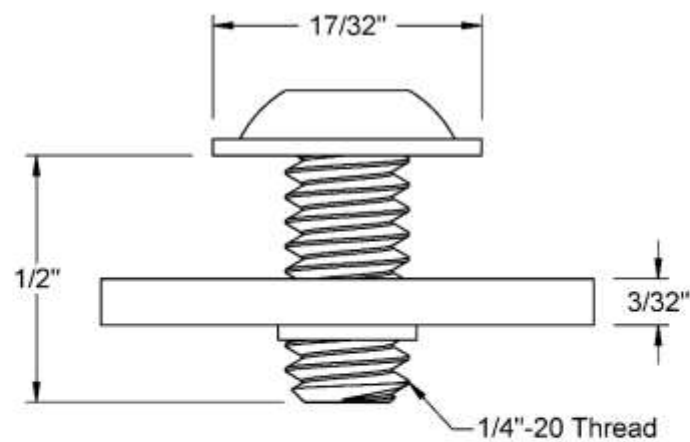
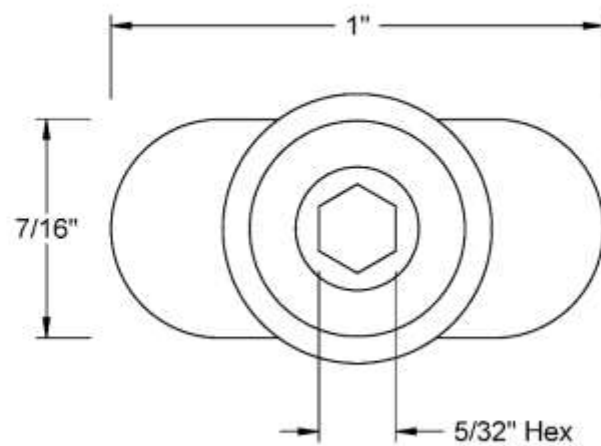
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	12028	BASKET FRONT PLATE	1
2	12029	BASKET SIDE PLATES	2
3	12030	BASKET BACK AND BASE PLATE	2
4	15267-12032	Zinc-Plated Steel Corner Bracket, 2" x 2" x 5/8"	12
5	12033	RHBOLT #6-32x0.75x0.75-N	48



NOTE: HOLES FOR BRACKETS DRILLED ON ASSEMBLY

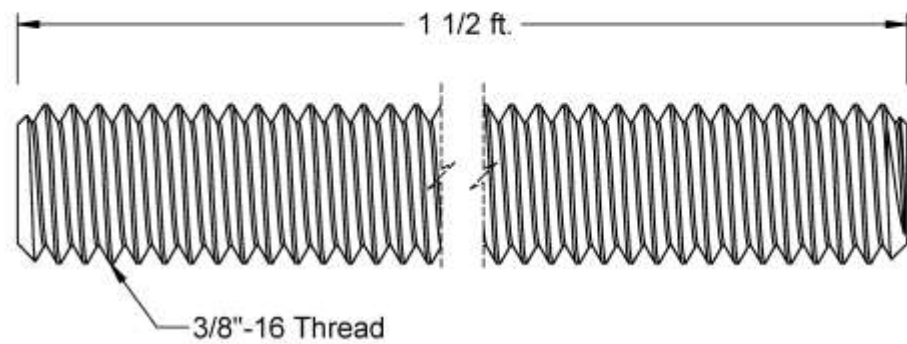
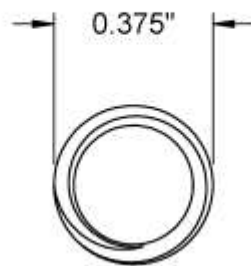
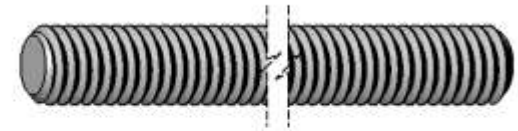


Cal Poly Mechanical Engineering ME 430 - SPRING 2018	Lab Section:	Assignment #	Title: BASKET ASSEMBLY		Drwn. By: TYLER NOXON
	Dwg. #:11004	Nxt Asb:	Date:	Scale: 1:5	Chkd. By: MESTAFF



McMASTER-CARR CAD
<http://www.mcmaster.com>
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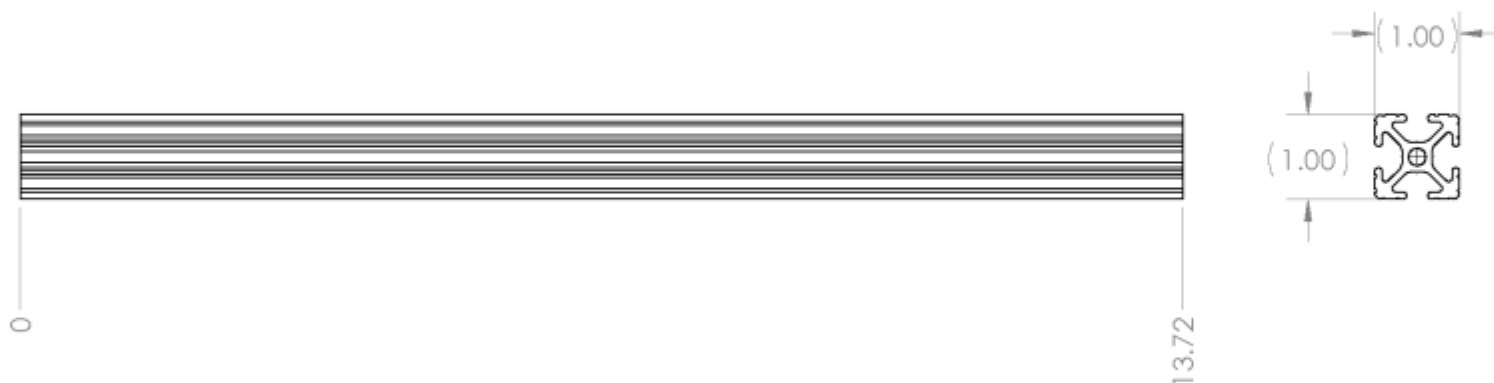
PART NUMBER **47065T142**
 End-Feed Fastener for
 Aluminum T-Slotted Framing



McMASTER-CARR <small>CAD</small>	PART NUMBER 98957A133
http://www.mcmaster.com © 2016 McMaster-Carr Supply Company <small>Information in this drawing is provided for reference only.</small>	Medium-Strength Steel Threaded Rod

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: 80/20 10SERIES ALUMINUM EXTRUSION
- 3.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 ANGLES = $\pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

Lab Section:
Dwg. #: 12001

Assignment #
Nxt Asb:

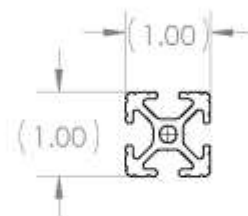
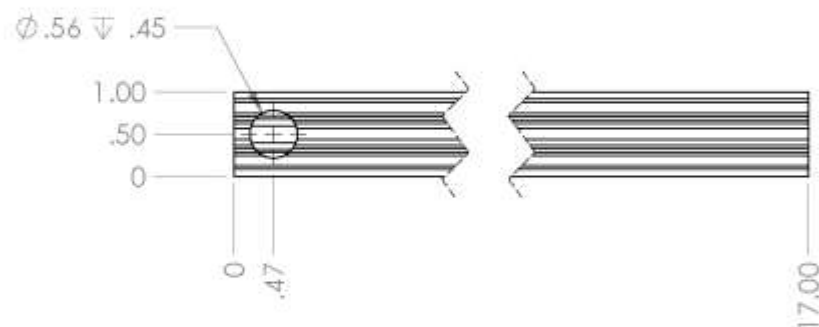
Title: REAR FRAME PIECE
Date:

Scale: 1:2

Drwn. By: TYLER NOXON
Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: 80/20 10SERIES ALUMINUM EXTRUSION
- 3.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 ANGLES = $\pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

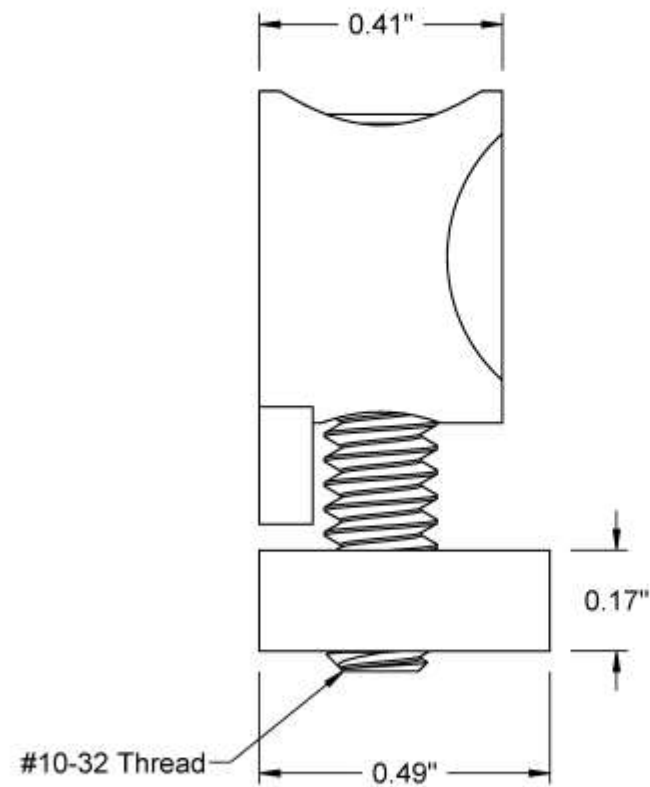
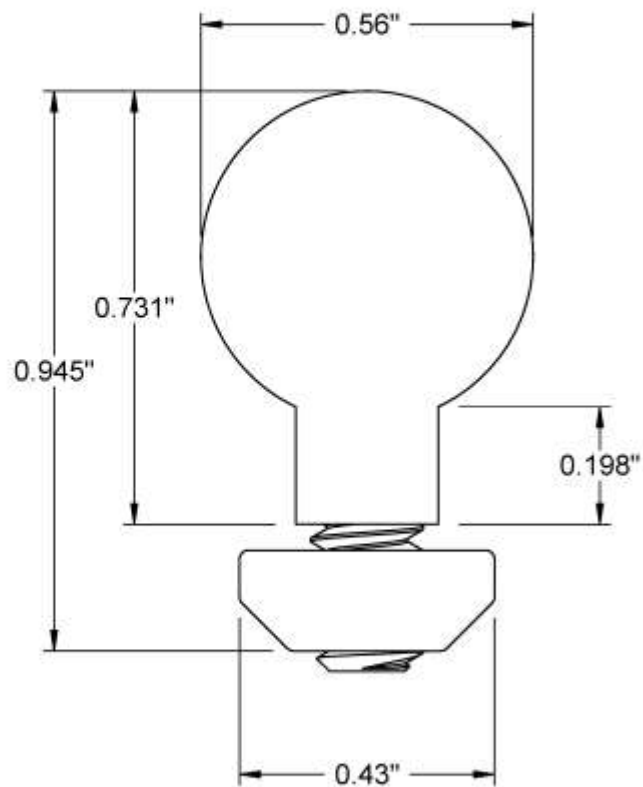
Lab Section:
Dwg. #: 12002

Assignment #
Nxt Asb:

Title: SIDE FRAME
Date:

Scale: 1:2

Drwn. By: TYLER NOXON
Chkd. By: ME STAFF

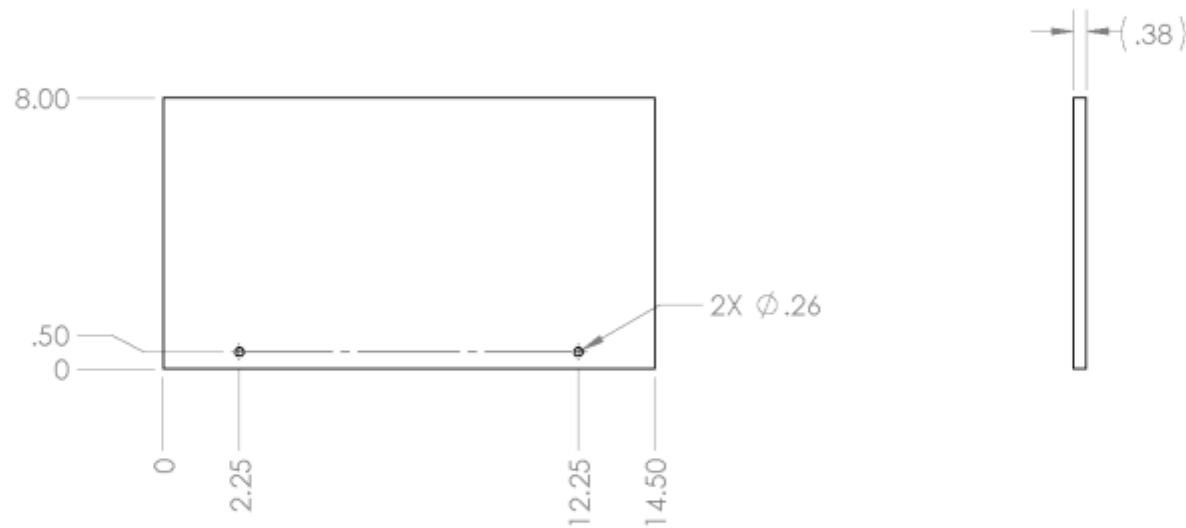


McMASTER-CARR CAD
<http://www.mcmaster.com>
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 Information in this drawing is provided for reference only.

PART NUMBER **47065T153**
 Adjustable Connector for
 Aluminum T-Slotted Framing

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: 3/8" HDPE SHEET
- 3.) LASER CUT DXF TO BE PROVIDED
- 4.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 $ANGLES = \pm 2^\circ$



Cal Poly Mechanical Engineering
 ME 430 - SPRING 2018

Lab Section:

Dwg. #: 12004

Assignment #

Nxt Asb:

Title: REAR SUPPORT PLATE

Date:

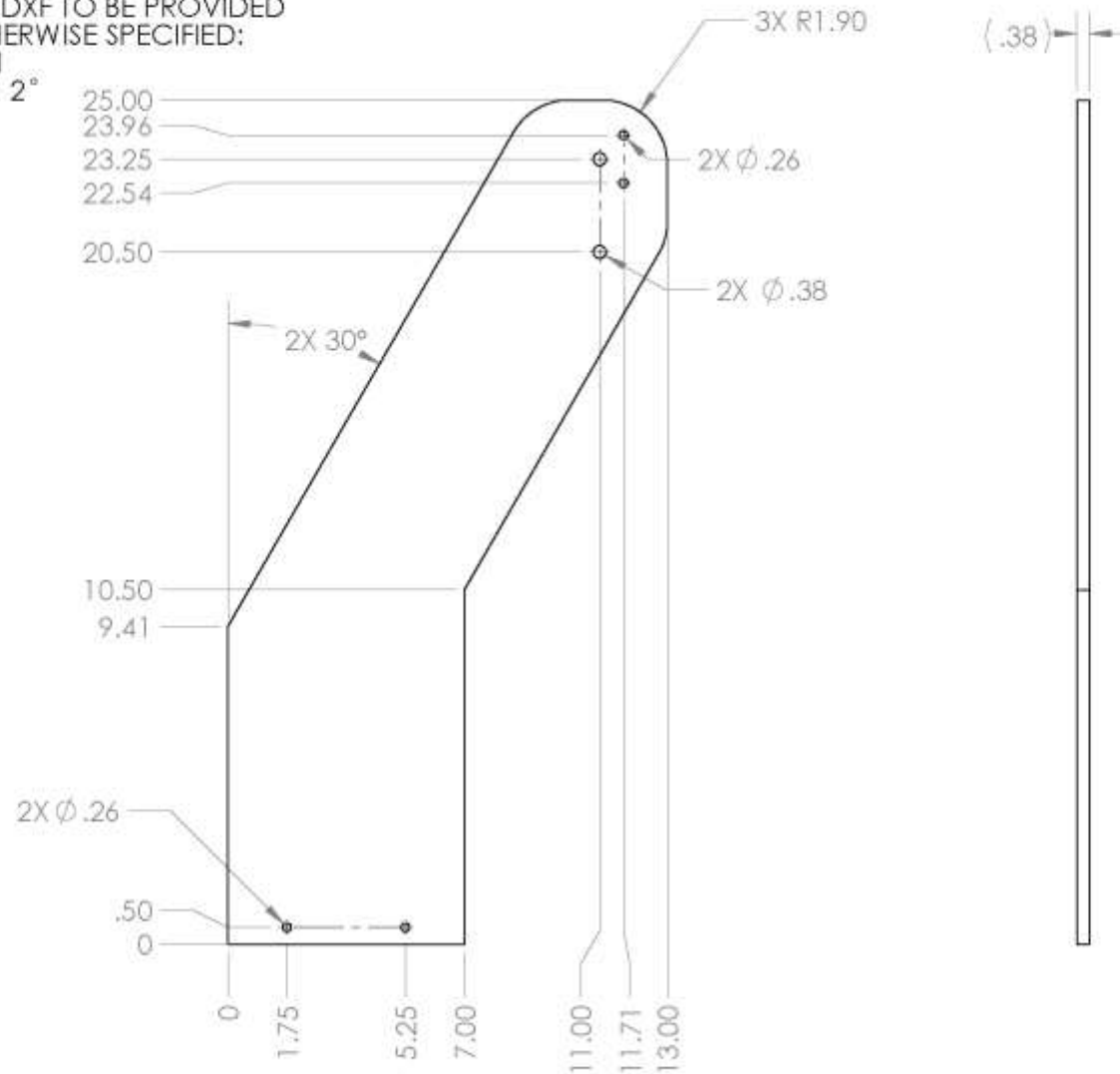
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Drwn. By: TYLER NOXON

Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: 3/8" HDPE SHEET
- 3.) LASER CUT DXF TO BE PROVIDED
- 4.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 ANGLES = $\pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

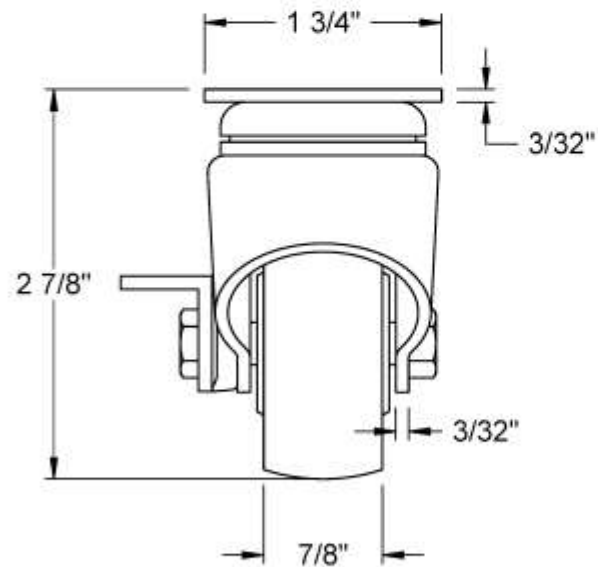
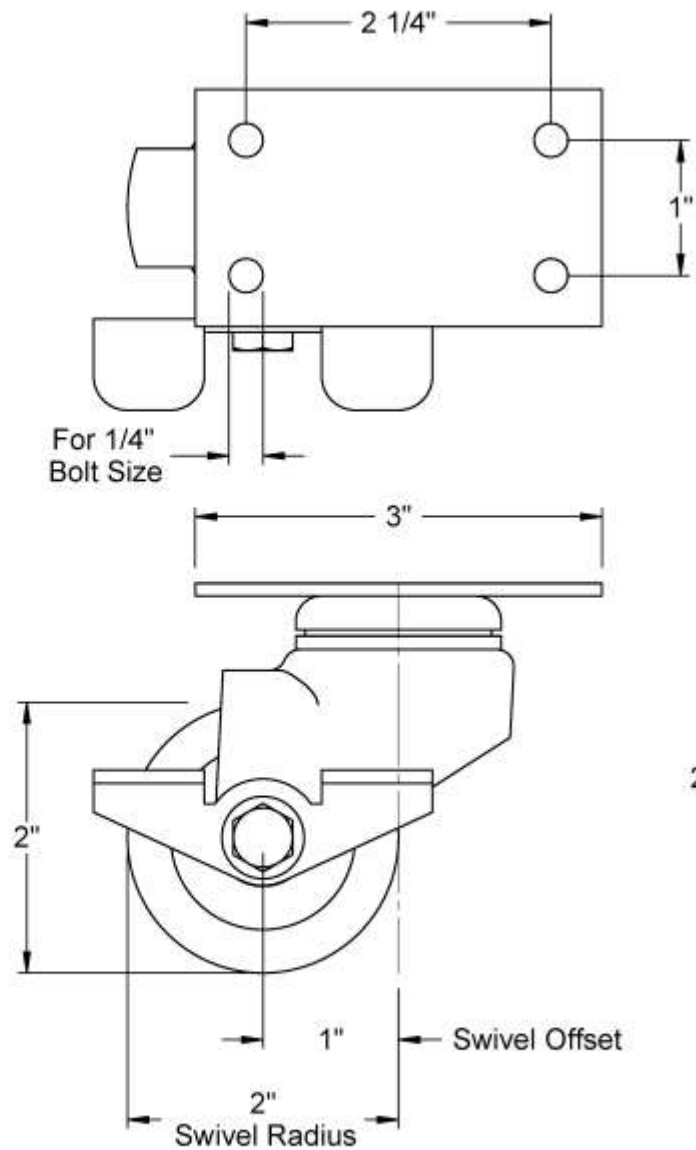
Lab Section:
Dwg. #: 12005

Assignment #
Nxt Asb:

Title: BODY BASKET SUPPORT
Date:

Scale: 1:5

Drwn. By: TYLER NOXON
Chkd. By: ME STAFF



McMASTER-CARR CAD
<http://www.mcmaster.com>
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 Information in this drawing is provided for reference only.

PART
NUMBER **2406T63**
 Mighty-Lite
 Swivel Caster with Brake

NOTES:

- 1.) VENDER: SEARSPARTSDIRECT.COM
- 2.) VENDER PART NUMBER = 10446



Cal Poly Mechanical Engineering ME 430 - SPRING 2018	Lab Section:	Assignment #	Title: DRIVE WHEEL		Drwn. By: TYLER NOXON
	Dwg. #:12007	Nxt Asb:	Date:	Scale: N/A	Chkd. By: ME STAFF

NOTES:

- 1.) VENDER: SEARSPARTSDIRECT.COM
- 2.) VENDER PART NUMBER = 30737 (30737-1 FOR LEFT)



Cal Poly Mechanical Engineering ME 430 - SPRING 2018	Lab Section:	Assignment #	Title: PINION GEAR		Drwn. By: TYLER NOXON
	Dwg. #:12008	Nxt Asb:	Date:	Scale: N/A	Chkd. By: ME STAFF

NOTES:

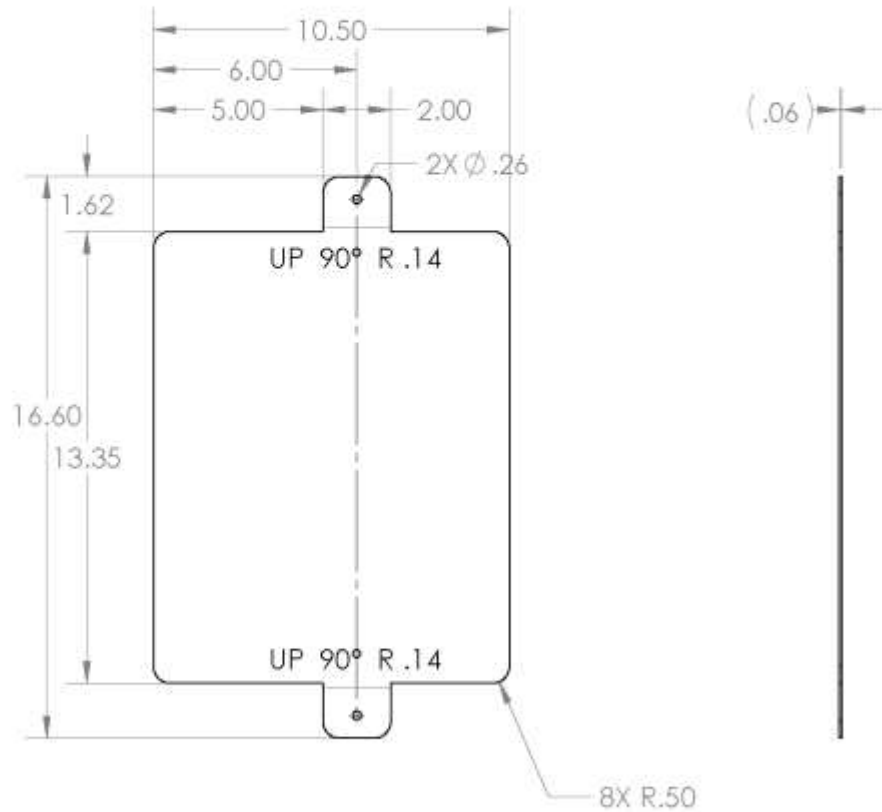
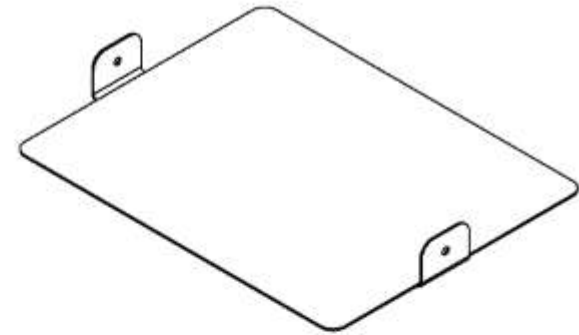
- 1.) VENDER: SEARSPARTSDIRECT.COM
- 2.) VENDER PART NUMBER = 30316



Cal Poly Mechanical Engineering ME 430 - SPRING 2018	Lab Section:	Assignment #	Title: RATCHET PAWL		Drwn. By: TYLER NOXON
	Dwg. #:12009	Nxt Asb:	Date:	Scale: N/A	Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: 16 GA STEEL SHEET
- 3.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 ANGLES = $\pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

Lab Section:
Dwg. #:12010

Assignment #
Nxt Asb:

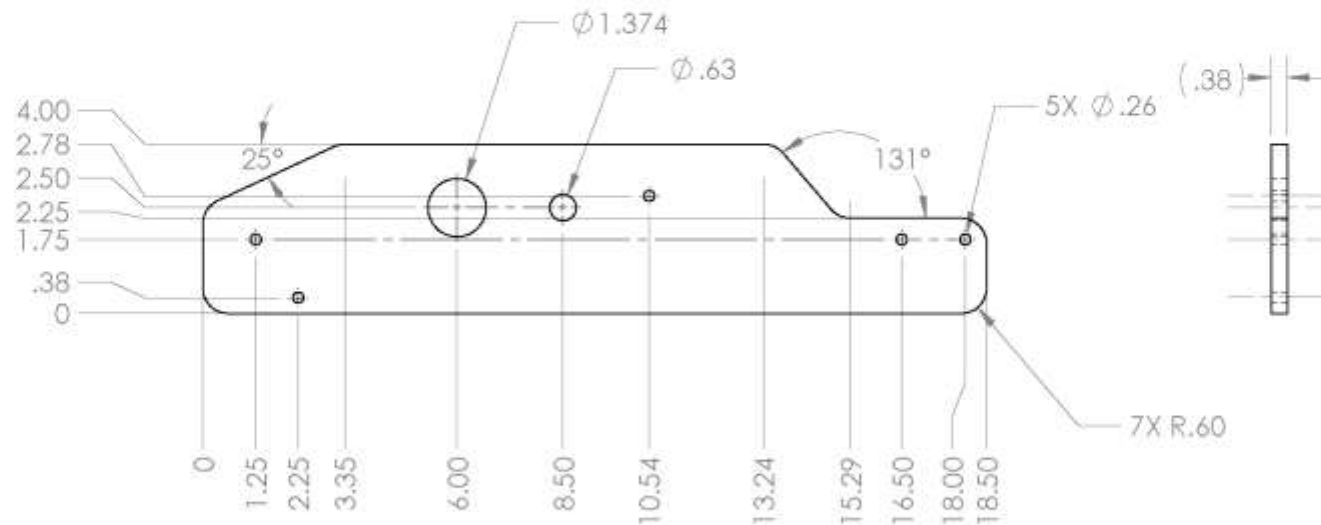
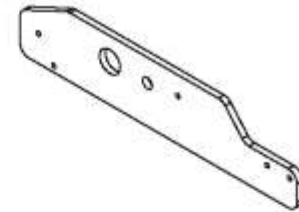
Title: BALL RAMP
Date:

Scale: 1:5

Drwn. By: TYLER NOXON
Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: 3/8" HDPE SHEET
- 3.) LASER CUT DXF TO BE PROVIDED
- 4.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 $X.XXX = \pm 0.001$
 $ANGLES = \pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

Lab Section:
Dwg. #: 12011

Assignment #
Nxt Asb:

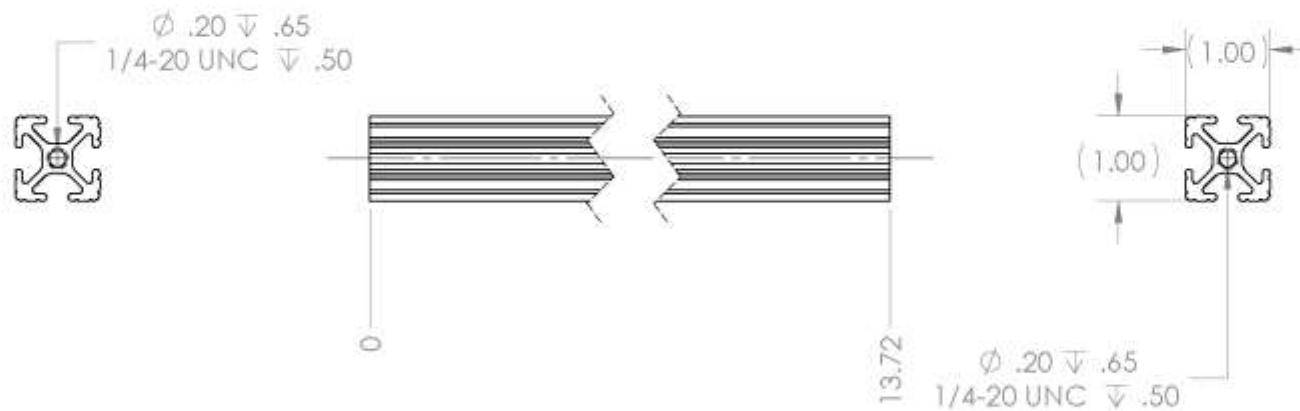
Title: BODY DRIVE SUPPORT
Date:

Scale: 1:4

Drwn. By: TYLER NOXON
Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: 80/20 10SERIES ALUMINUM EXTRUSION
- 3.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 $ANGLES = \pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

Lab Section:

Dwg. #: 12014

Assignment #

Nxt Asb:

Title: FRONT FRAME PIECE

Date:

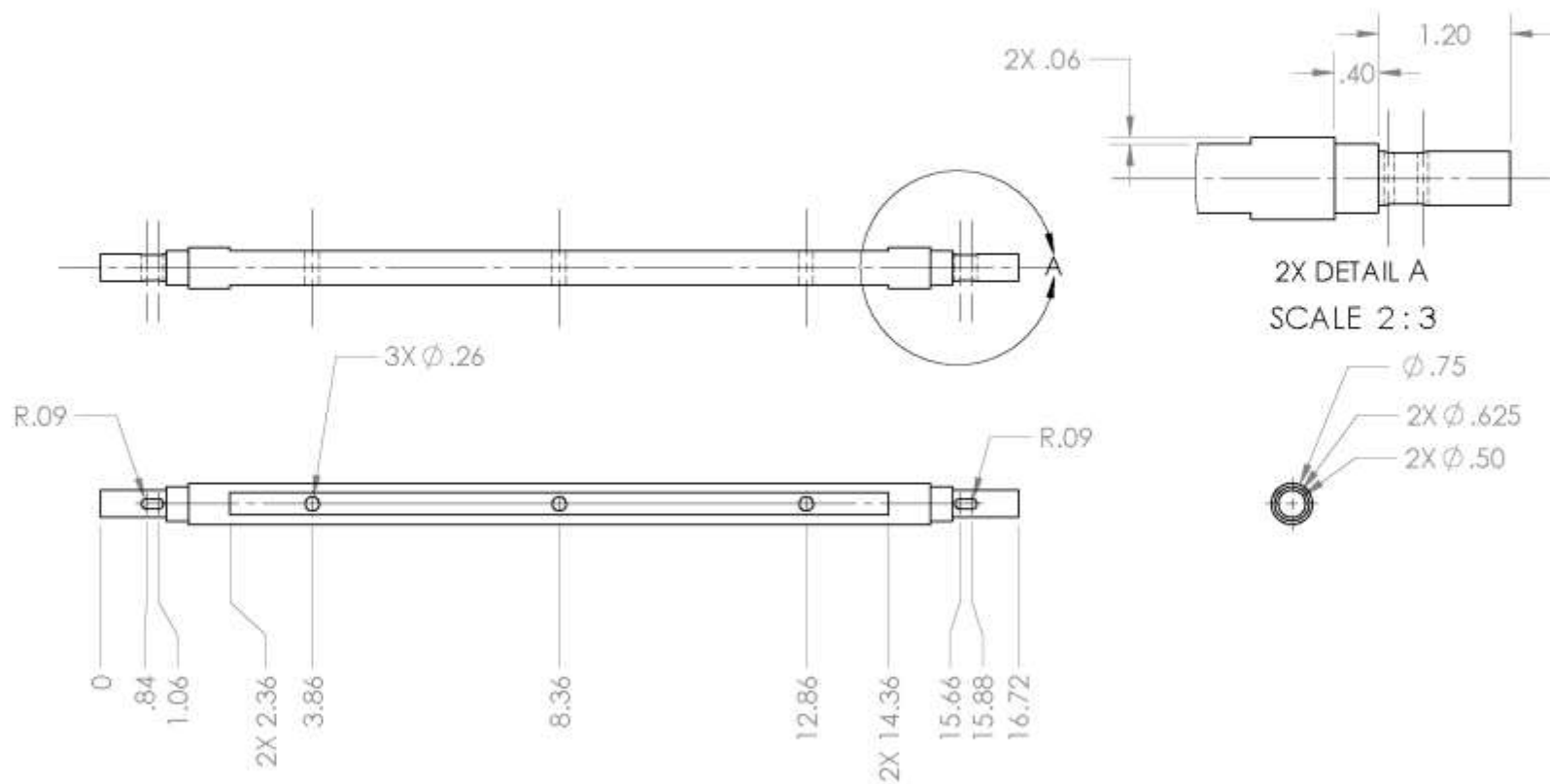
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Drwn. By: TYLER NOXON

Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: .75 IN 6061 ALUMINUM ROUND STOCK
- 3.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 $X.XXX = \pm 0.001$
 ANGLES = $\pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

Lab Section:

Assignment #

Title: DRIVE SHAFT

Drwn. By: TYLER NOXON

Dwg. #: 12015

Nxt Asb:

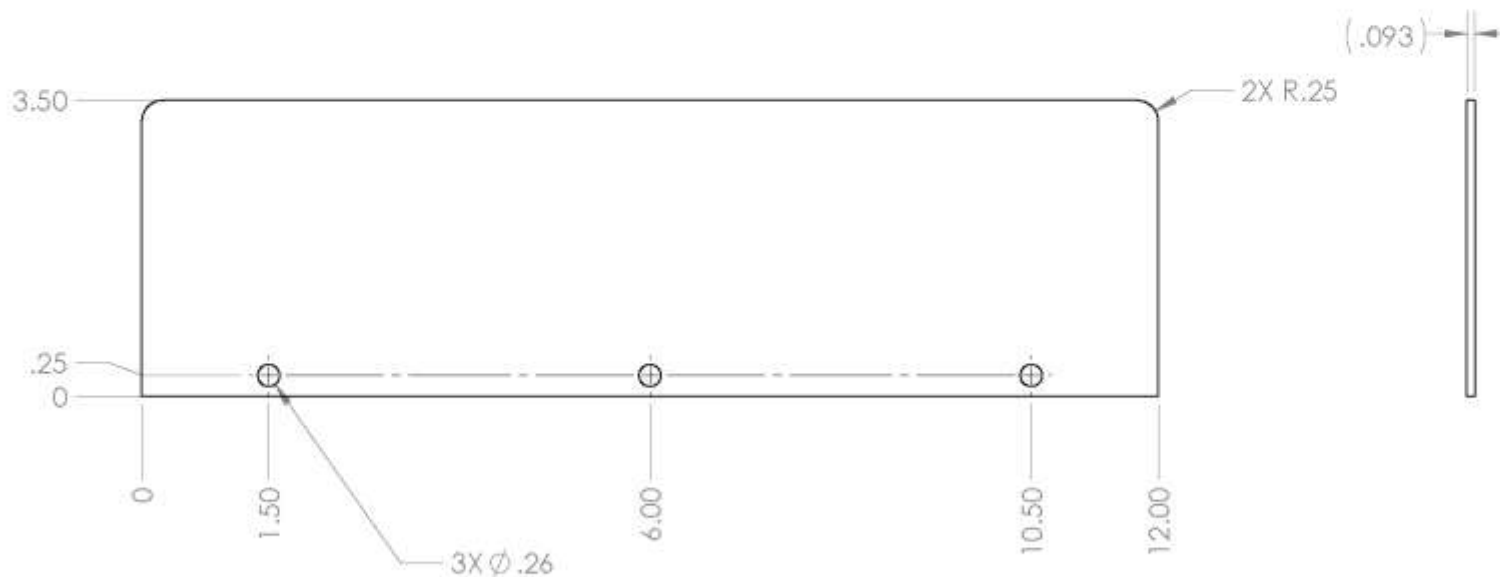
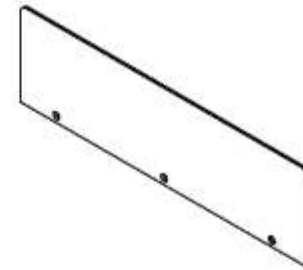
Date:

Scale: 1:3

Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: .093 CLEAR POLYCARBONATE SHEET
- 3.) LASER CUT DXF TO BE PROVIDED
- 4.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 $X.XXX = \pm 0.001$
 ANGLES = $\pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

Lab Section:
Dwg. #: 12016

Assignment #
Nxt Asb:

Title: PADDLE FIN
Date:

Scale: 1:2

Drwn. By: TYLER NOXON
Chkd. By: ME STAFF

NOTES:

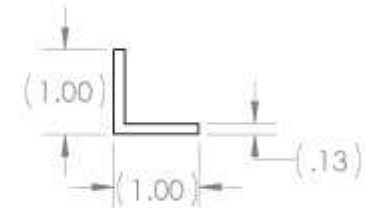
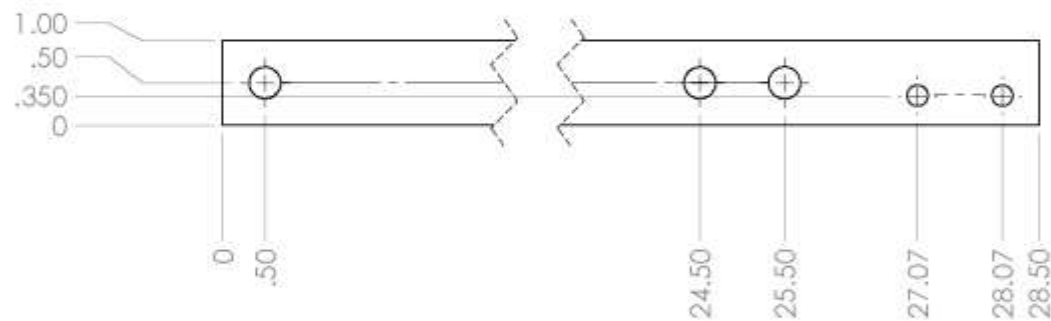
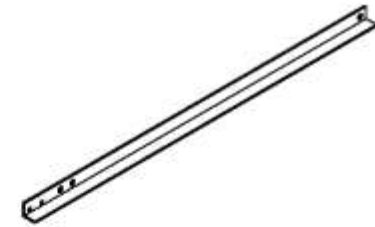
- 1.) VENDER: HOMEDEPOT.COM
- 2.) VENDER PART NUMBER = 03_167_W_WR_04



Cal Poly Mechanical Engineering ME 430 - SPRING 2018	Lab Section:	Assignment #	Title: PADDLE FIN COATING		Drwn. By: TYLER NOXON
	Dwg. #:12017	Nxt Asb:	Date:	Scale: N/A	Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: ALUMINUM ANGLE STOCK 1"X.125
- 3.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 $X.XXX = \pm 0.005$
 ANGLES = $\pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

Lab Section:
Dwg. #: 12018

Assignment #
Nxt Asb:

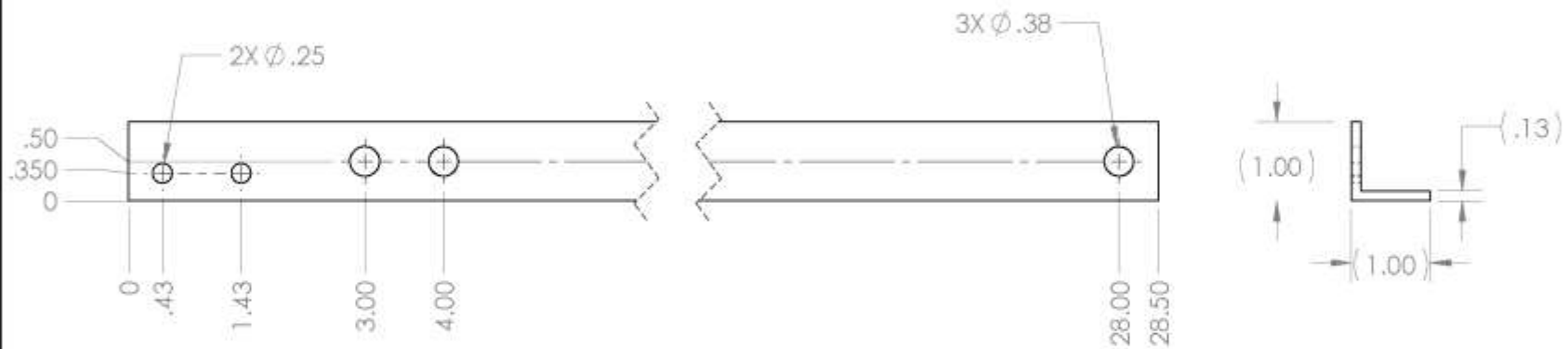
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Date:

Scale: 1:2

Drwn. By: TYLER NOXON
Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: ALUMINUM ANGLE STOCK 1"X.125
- 3.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 $X.XXX = \pm 0.005$
 ANGLES = $\pm 2^\circ$



Cal Poly Mechanical Engineering
ME430 - SPRING 2018

Lab Section:
Dwg. #: 12019

Assignment #
Nxt Asb:

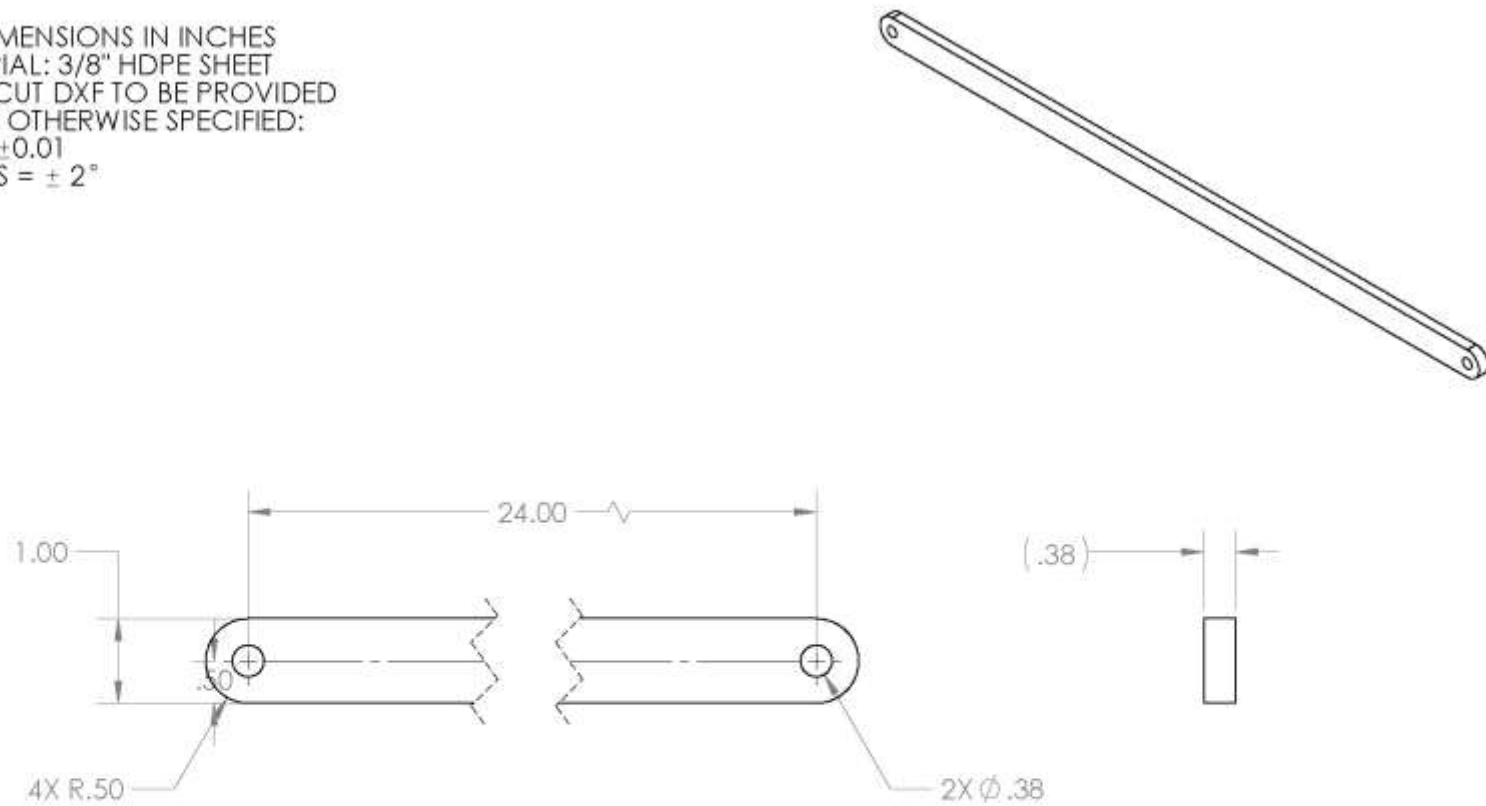
Title: UPPER LINKAGE RIGHT
Date:

Scale: 1:2

Drwn. By: TYLER NOXON
Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: 3/8" HDPE SHEET
- 3.) LASER CUT DXF TO BE PROVIDED
- 4.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 ANGLES = $\pm 2^\circ$



Cal Poly Mechanical Engineering
ME430 - SPRING 2018

Lab Section:
Dwg. #: 12020

Assignment #
Nxt Asb:

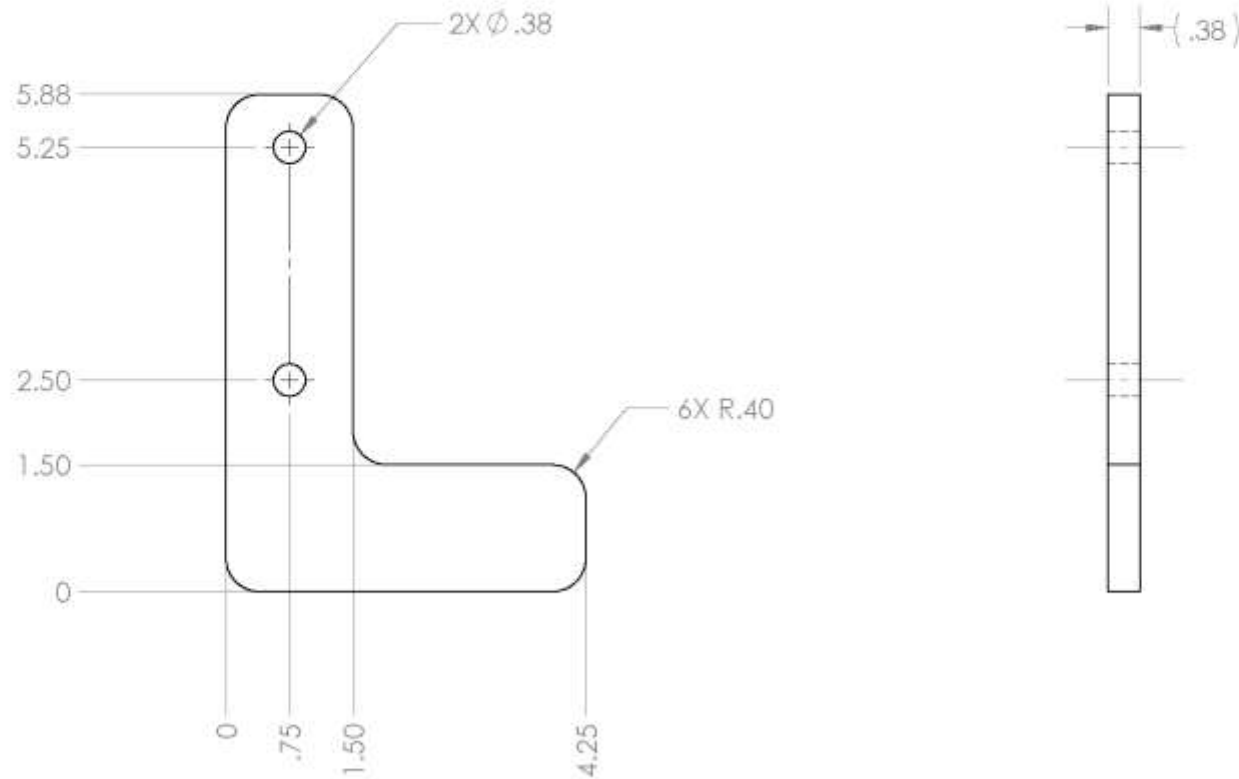
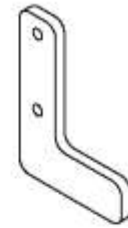
Title: Lower Linkage
Date:

Scale: 1:2

Drwn. By: TYLER NOXON
Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: 3/8" HDPE SHEET
- 3.) LASER CUT DXF TO BE PROVIDED
- 4.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 $ANGLES = \pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

Lab Section:
Dwg. #: 12024

Assignment #
Nxt Asb:

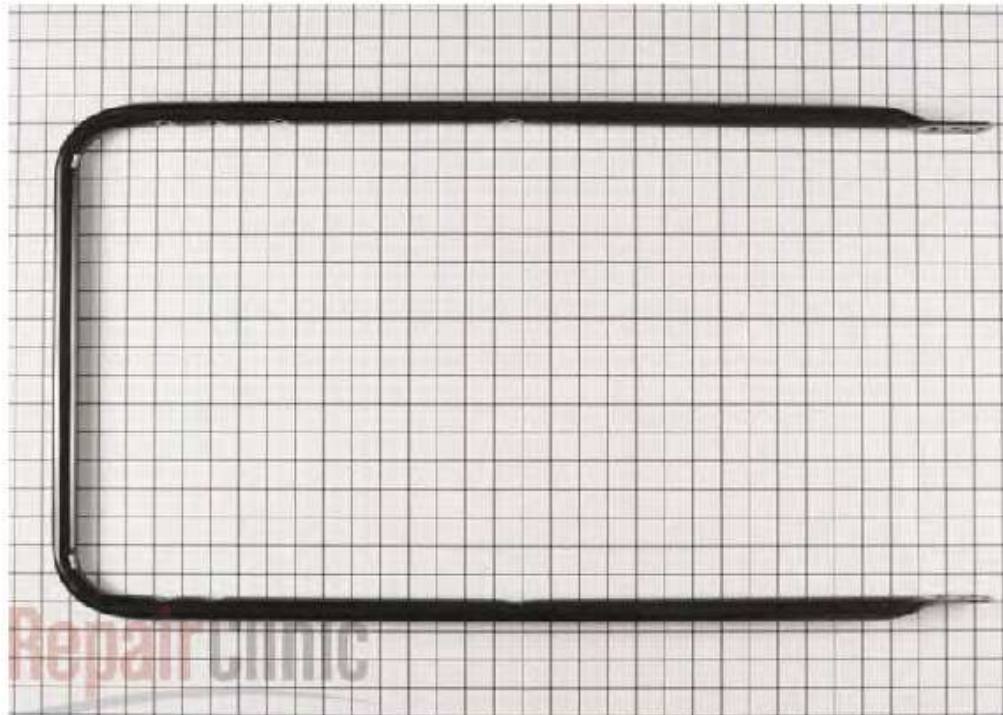
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Date:

Scale: 1:2

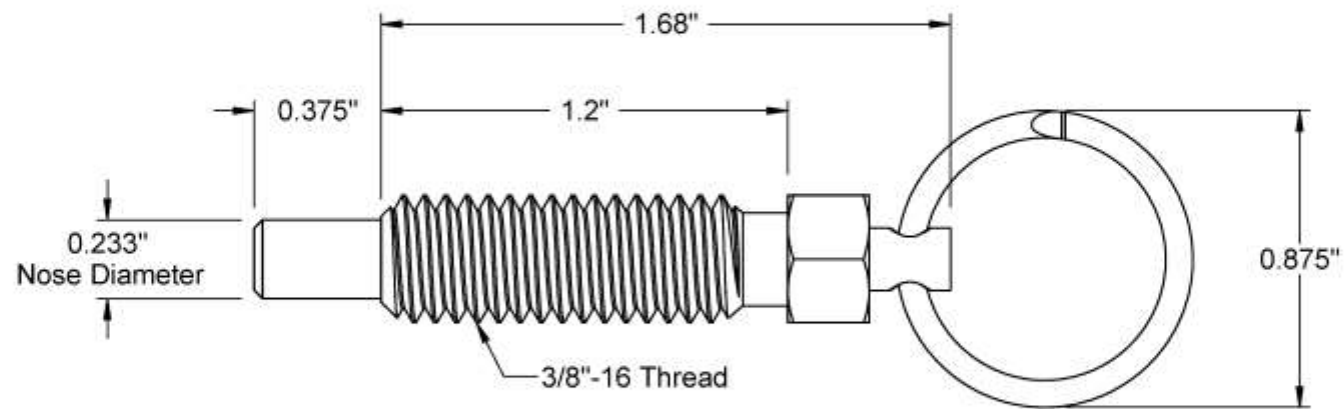
Drwn. By: TYLER NOXON
Chkd. By: ME STAFF

NOTES:

- 1.) VENDER: REPAIRCLINIC.COM
- 2.) VENDER PART NUMBER = 4502759



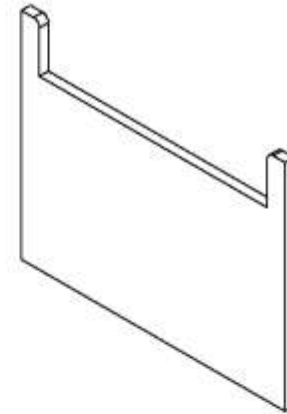
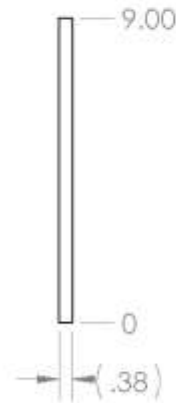
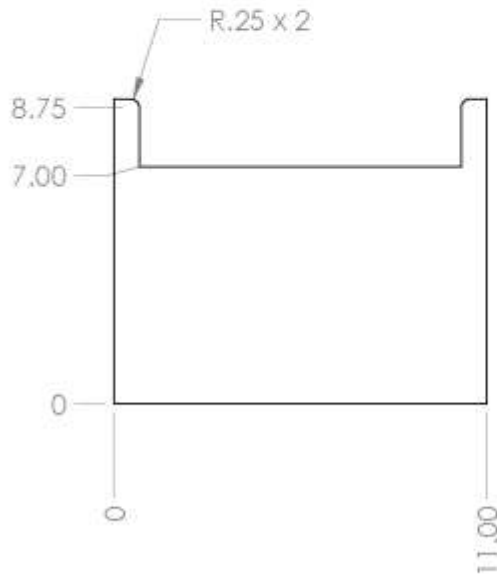
Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: HANDLE BAR	Drwn. By: TYLER NOXON
ME 430 - SPRING 2018	Dwg. #:12026	Nxt Asb:	Date:	Scale: N/A
				Chkd. By: ME STAFF



McMASTER-CARR <small>CAD</small> http://www.mcmaster.com © 2012 McMaster-Carr Supply Company <small>Information in this drawing is provided for reference only.</small>	PART NUMBER 8482A421
	Corrosion-Resistant Retractable Spring Plunger without Locking Nose

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: 3/8" HDPE SHEET
- 3.) LASER CUT DXF TO BE PROVIDED
- 4.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 $ANGLES = \pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 18'

Lab Section:
Dwg. #: 12028

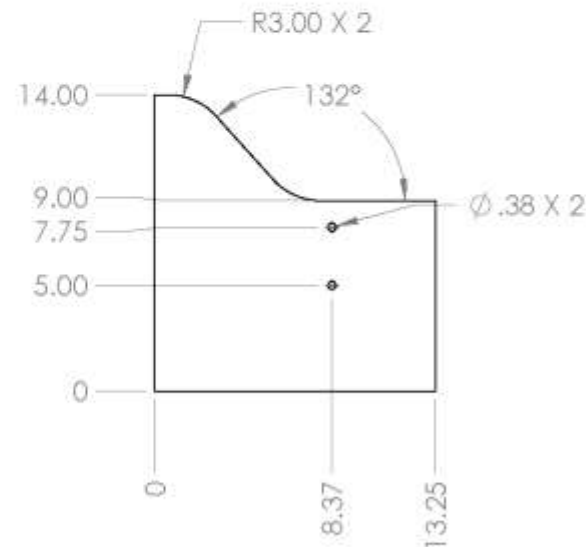
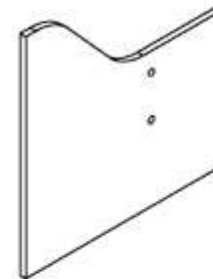
Assignment #
Nxt Asb:

Title: FRONT PLATE OF BIN
Date: 06/01/2018 Scale: 1:5

Drwn. By: ALEX MORALES
Chkd. By: ME STAFF

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: 3/8" HDPE SHEET
- 3.) LASER CUT DXF TO BE PROVIDED
- 4.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 $ANGLES = \pm 2^\circ$



Cal Poly Mechanical Engineering
 ME 430 - SPRING 18'

Lab Section:
 Dwg. #: 12029

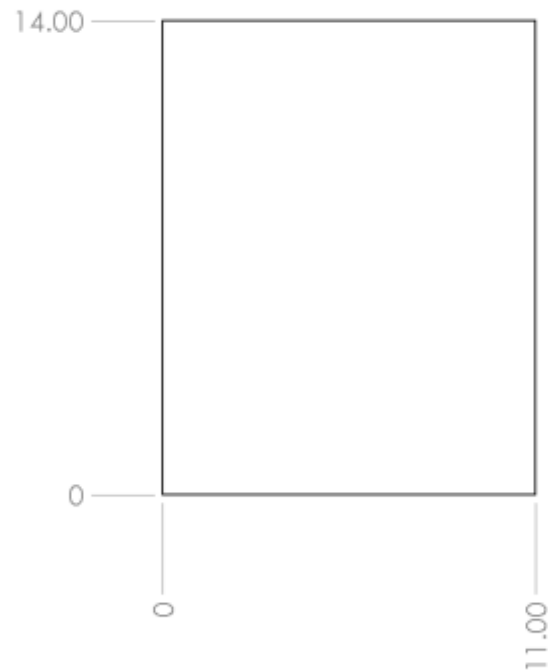
Assignment #
 Nxt Asb:

Title: SIDE PLATES OF BIN
 Date: 06/01/2018 Scale: 1:8

Drwn. By: ALEX MORALES
 Chkd. By:

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: 3/8" HDPE SHEET
- 3.) LASER CUT DXF TO BE PROVIDED
- 4.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 $ANGLES = \pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 18'

Lab Section: 02

Dwg. #:12030

Assignment #

Nxt Asb:

Title: BACK/BOTTOM PLATE

Date: 06/01/2018

Scale:1:5

Drwn. By: ALEX MORALES

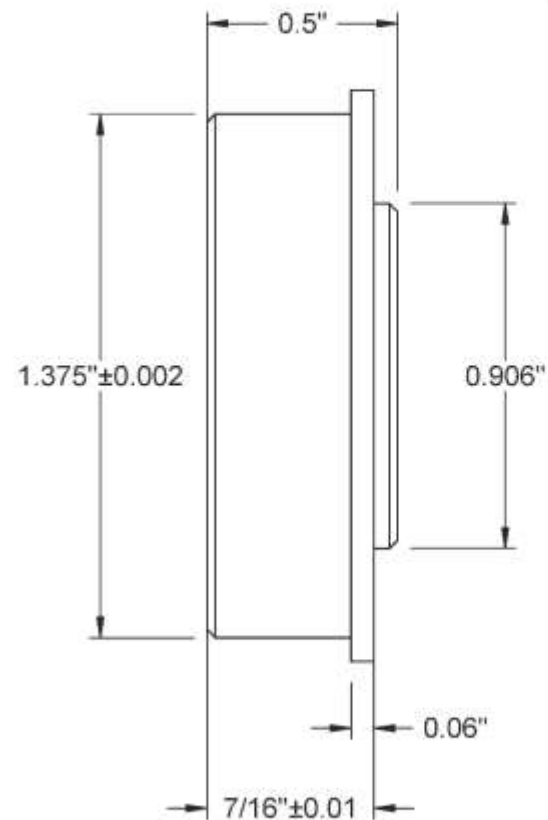
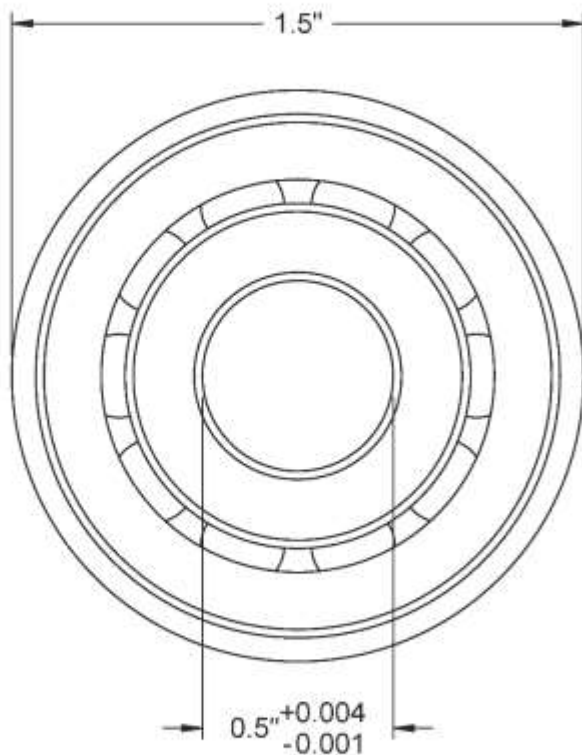
Chkd. By: ME

NOTES:

- 1.) VENDER: HOMEDEPOT.COM
- 2.) VENDER PART NUMBER = 15267



Cal Poly Mechanical Engineering ME 430 - SPRING 2018	Lab Section:	Assignment #	Title: L-BRACKET, 2IN		Drwn. By: TYLER NOXON
	Dwg. #:12032	Nxt Asb:	Date:	Scale: N/A	Chkd. By: ME STAFF



McMASTER-CARR CAD

<http://www.mcmaster.com>
 © 2017 McMaster-Carr Supply Company
 Information in this drawing is provided for reference only.

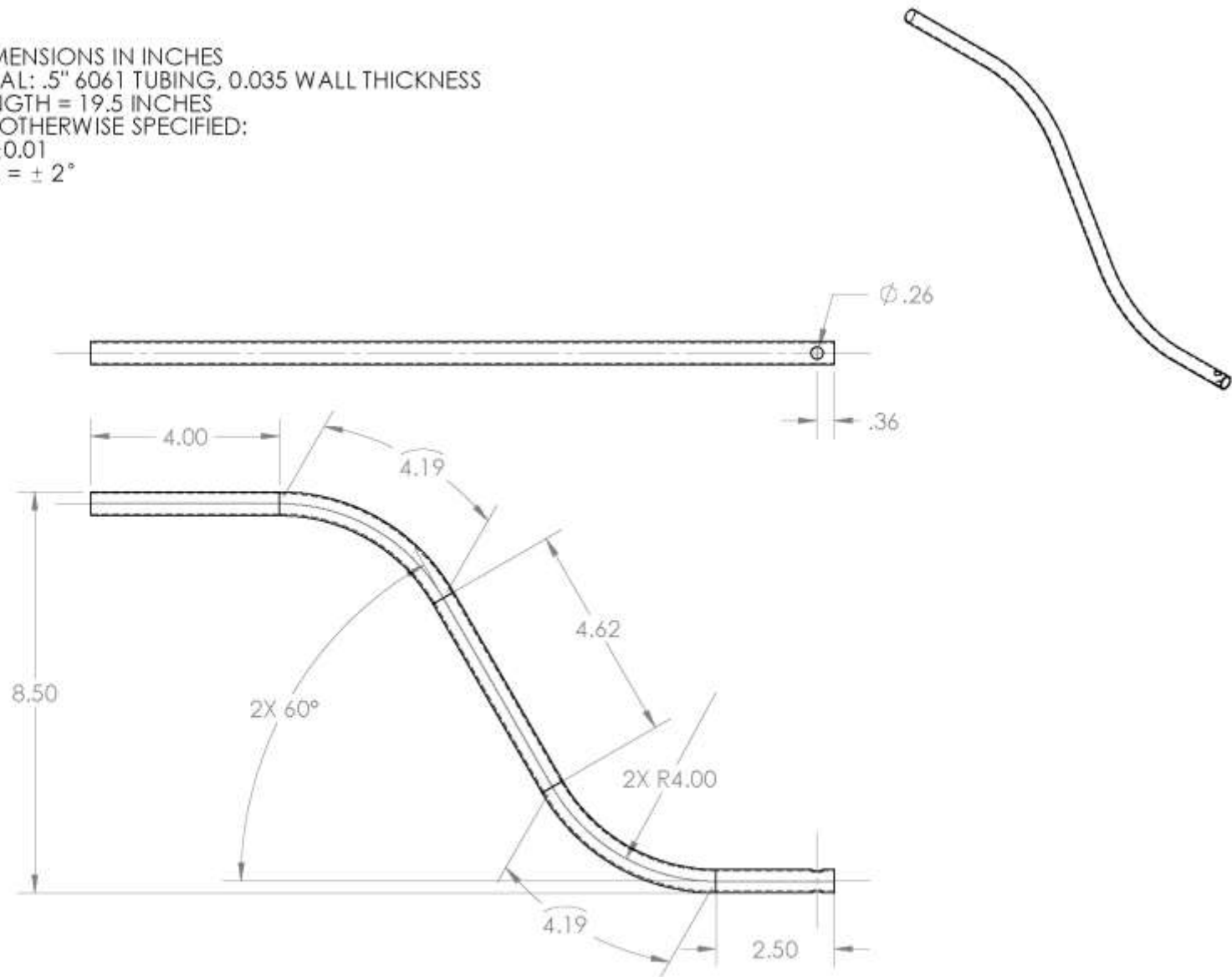
PART
NUMBER

6383K241

Flanged
Ball Bearing

NOTES:

- 1.) ALL DIMENSIONS IN INCHES
- 2.) MATERIAL: .5" 6061 TUBING, 0.035 WALL THICKNESS
- 3.) CUT LENGTH = 19.5 INCHES
- 4.) UNLESS OTHERWISE SPECIFIED:
 $X.XX = \pm 0.01$
 $ANGLES = \pm 2^\circ$



Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

Lab Section:

Dwg. #: 12035

Assignment #

Nxt Asb:

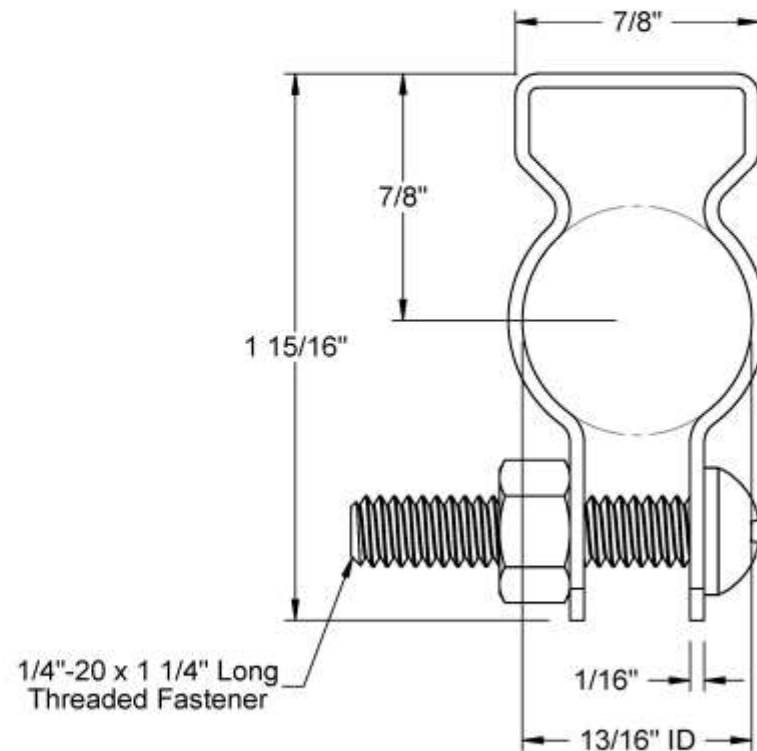
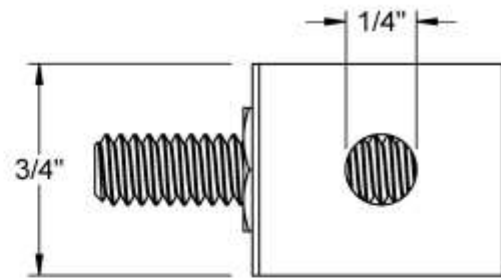
Title: GATHERING ARMS

Date:

Scale: 1:3

Drwn. By: TYLER NOXON

Chkd. By: ME STAFF



McMASTER-CARR CAD
<http://www.mcmaster.com>
 © 2016 McMaster-Carr Supply Company
 Information in this drawing is provided for reference only.

PART NUMBER	3006T78
	Clamping Hanger

Appendix G

Purchased Parts Details

Table G.1. Link specifications of all parts needed for the Paddlewheel Mechanism

Purchased Part Detail List			
Paddlewheel Mechanism			
Part	Vendor	Vendor Part #	Website Link
Handle Bar	Repair Clinic	4502759	https://www.repairclinic.com/PartDetail/Handle/74905084A0637/4502759
Handle Bail Rod	Repair Clinic	1926176	https://www.repairclinic.com/PartDetail/Bail-Control-Arm/532194177/1926176
Cable	Repair Clinic	2426136	https://www.repairclinic.com/PartDetail/Control-Cable/532176556/2426136
Drive Wheel	Sears Parts Direct	193912X427	https://www.searspartsdirect.com/part-number/180773/0071/917.html?bpBrandId=&bpCategoryId=1500600&bpPartType=&bpSubType=Wheels
Pinion Gear	Sears Parts Direct	31053	https://www.searspartsdirect.com/part-number/31053/0071/291.html
Ratchet Pawl	Sears Parts Direct	30316	https://www.searspartsdirect.com/part-number/30316/0071/291.html
Cable Lock	McMaster-Carr	8691A48	https://www.mcmaster.com/#8691a48/=1bjjpuz
80/20 3ft	McMaster-Carr	47065T101	https://www.mcmaster.com/#47065t101/=1bj8pca
80/20 2ft	McMaster-Carr	47065T101	https://www.mcmaster.com/#47065t101/=1bj8pca
Bolts	McMaster-Carr	92196A057	https://www.mcmaster.com/#92196a057/=1bj8pn4
Lock Nuts	McMaster-Carr	91831A002	https://www.mcmaster.com/#91831a002/=1bj8puc
Brushes	McMaster-Carr	7900T1	https://www.mcmaster.com/#7900t1/=1bjirqi
HDPE Plastic	Interstate Plastics	N/A	https://www.interstateplastics.com/Hdpe-Natural-Sheet-HDPNE~SH.php?sku=HDPNE++SH&vid=20180212041541-3p&dim2=22&dim3=46&thickness=0.375&qty=2&recalculate.x=0&recalc
Castor Wheels	Harbor Freight	41518	https://www.harborfreight.com/2-inch-x-7-8-eighth-inch-light-duty-swivel-caster-41518.html
Basket	Target	N/A	https://www.target.com/s/plastic%20storage%20drawers#Nao=0&facetedValue=4ym9k&sortBy=relevance&og=plastic%20storage%20drawers

Table G.2. Link specifications of all parts needed for the Paddlewheel Mechanism

Belt Drive Mechanism			
Part	Vendor	Vendor Part #	Website Link
Conveyor Roller	McMaster-Carr	2277T56	https://www.mcmaster.com/#2277t56/=1bj6sgj
Lift Belt	McMaster-Carr	5751K301	https://www.mcmaster.com/#5751k301/=1bj6sq1
Alligator Lacing	McMaster-Carr	6116K102	https://www.mcmaster.com/#6116k102/=1bj6sv6
Drive Belt	McMaster-Carr	8060K199	https://www.mcmaster.com/#8060k199/=1bj6t3z
Bearing Mounts	McMaster-Carr	5912K400	https://www.mcmaster.com/#5912k4/=1bj6tch
Key	McMaster-Carr	98493A100	https://www.mcmaster.com/#98493a100/=1bj6thm
Belt Pulley	McMaster-Carr	6284K560	https://www.mcmaster.com/#6284k56/=1bj6tm1
Bin	Target	N/A	https://www.target.com/s/plastic%20storage%20drawers#Nao=0&facetedValue=4ym9k&sortBy=relevance&og=plastic%20storage%20drawers
Bolts	McMaster-Carr	92198A437	https://www.mcmaster.com/#92198a437/=1bj6u1y
Hex Nuts	McMaster-Carr	91847A525	https://www.mcmaster.com/#91847a525/=1bj6u75
Lock Nuts	McMaster-Carr	91831A140	https://www.mcmaster.com/#91831a140/=1bj6uey
Screws	McMaster-Carr	92325A317	https://www.mcmaster.com/#92325a317/=1bj6ujg
HDPE Sheets	Interstate Plastics	N/A	https://www.interstateplastics.com/Hdpe-Natural-Sheet-HDPNE~SH.php?sku=HDPNE++SH&vid=20180212040937-5p&dim2=48&dim3=24&thickness=0.500&qty=1

Appendix H

Budget/Procurement List

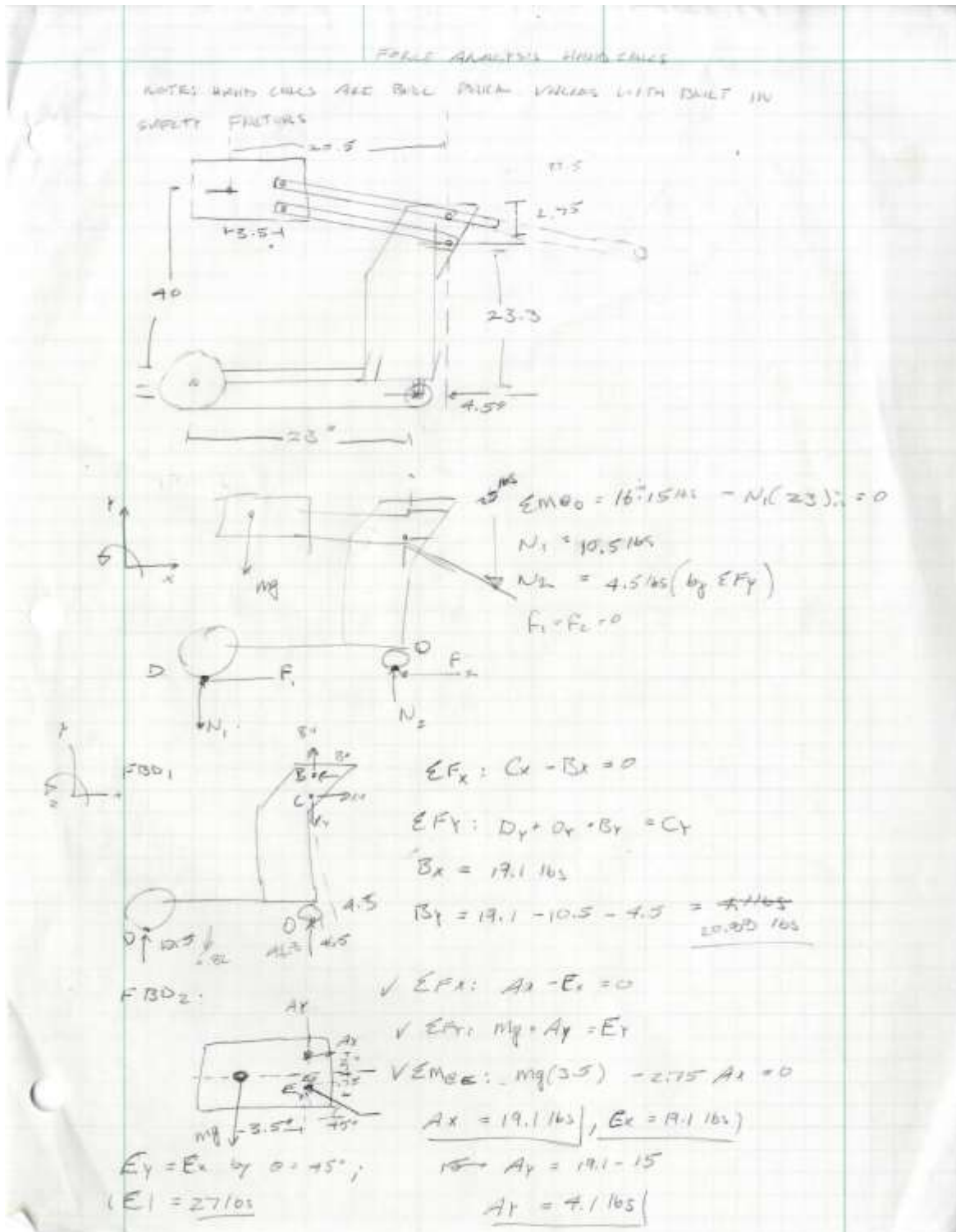
Table H.1. List of all parts needed including vendors and final budget remaining

Budget					
Paddlewheel Mechanism					
Part	Vendor	Vendor Part #	Cost	Quantity	Total Cost
80/20 10ft	McMaster-Carr	47065T101	\$8.35	1	\$16.00
Socket Head Screws	McMaster-Carr	92185A542	\$3.91	3	\$11.73
Aluminum Shaft(6ft)	McMaster-Carr	8974K11	\$21.13	1	\$21.13
Brush	McMaster-Carr	7900T2	\$13.17	1	\$13.17
Brush Holder	McMaster-Carr	7900T34	\$7.51	1	\$7.51
Castor Wheels	McMaster-Carr	78155T14	\$4.40	2	\$8.80
T-Slot Fasteners	McMaster-Carr	47065T142	\$2.30	7	\$16.10
T-Slot Anchors	McMaster-Carr	47065T153	\$3.39	4	\$13.56
Pull-Ring Retractable Spring	McMaster-Carr	8482A42	\$10.77	2	\$21.54
Bearing Mounts*	Central Coast Bearing	AF-4044	\$9.05	2	\$18.11
HDPE Sheets	Polymersan	N/A	-	-	\$115.15
				Total	\$262.80
Belt Drive Mechanism					
Part	Vendor	Vendor Part #	Cost	Quantity	Total Cost
Conveyor Roller	McMaster-Carr	2277T56	\$ 12.74	2	\$ 25.48
Lift Belt	McMaster-Carr	5751K301	\$ 78.48	1	\$ 78.48
Alligator Lacing	McMaster-Carr	6110K133	\$ 46.38	1	\$ 46.38
Drive Belt 21.5"	McMaster-Carr	8060K206	\$ 4.35	1	\$ 4.35
Drive Belt 23"	McMaster-Carr	8060K38	\$ 9.57	1	\$ 9.57
Bearing Mounts	McMaster-Carr	3813T2	\$ 3.70	2	\$ 7.40
Key	McMaster-Carr	98830A100	\$ 0.68	1	\$ 0.68
Belt Pulley	McMaster-Carr	6284K56	\$ 20.75	1	\$ 20.75
Bin	Target	N/A	\$ 10.00	1	\$ 10.00
Hex Head Screws	McMaster-Carr	92198A437	\$ 5.44	4	\$ 21.76
Hex Nut	McMaster-Carr	91847A525	\$ 6.36	4	\$ 25.44
Lock Nut	McMaster-Carr	91831A140	\$ 6.86	4	\$ 27.44
HDPE Sheets	Polymersan	N/A	-	-	\$ 125.98
				Total	\$ 403.71

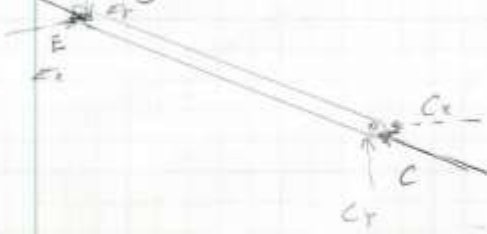
Project Budegt	\$1,400
Spent	\$666.51
Remaining	\$733.49

Appendix I

Final Analyses Calculations



FBD 3: LOWER LINK:



$$E_x = C_x$$

$$E_y = C_y$$

FBD 4:



$$\sum M_B = 0$$

$$A_y = 4.1 \text{ lbs}$$

$$B_y = 20.88 \text{ lbs}$$

$$\sum F_y = 20.88 - 4.1 - 2.6 = 0$$

$$C_{Fy} = 0$$

$$A_x = 19.1 \text{ lbs}$$

$$\sum M_B = 0$$

$$0 = -A_y (27 \cos 45) + A_x (27 \sin 45) - F (27.5 \cos 45) + M$$

$$0 = M + 324.7 \text{ lb} \cdot \text{in} - 69.7 - 397.75$$

$$M = 142.75 \text{ lb} \cdot \text{in}$$

STRESS ANALYSIS

- LEVER ARM

$\frac{5}{8} \times 1$

- From Force Analysis
on Link

$$A_x \approx B_x \approx 19.1 \text{ lbs}$$

$$A_y = 4.1 \text{ lbs}$$

$$B_y = 20.88 \text{ lbs}$$

CROSS-SECTION

* CHOSEN DIMENSIONS



$$\sum M_o = M - (25 \text{ lbs})(22.5 \cos(45^\circ)) + A_x(24 \sin(45^\circ)) - A_y(24 \cos(45^\circ)) = 0$$

$$M = (25)(22.5 \cos(45^\circ)) + (4.1 \text{ lbs})(24 \cos(45^\circ)) - (19.1)(24 \sin(45^\circ))$$

$$M \approx 144 \text{ lb-in}$$

→ MAX BENDING STRESS

$$\sigma_{max} = \frac{Mc}{I}$$

$$I = \frac{1}{12} (0.375 \text{ in})(1 \text{ in})^3$$

$$I = 0.03125 \text{ in}^4$$

$$\sigma_{max} = \frac{(144 \text{ lb-in}) \left(\frac{1 \text{ in}}{2} \right)}{0.03125 \text{ in}^4}$$

$$\sigma_{max} = 2,304 \text{ psi}$$

→ MAX SHEAR STRESS

$$\tau_{max} = \frac{3V}{2A}$$

$$= \frac{3(25 \text{ lb})}{2(0.375)(1)}$$

$$\tau_{max} = 100 \text{ psi}$$

*NOTE: Stresses are distributed between two grains. Therefore, a safety factor of 2 is included.

$$A_y = B_y = 10$$

$$A_x = B_x = 25 \text{ lbs}$$

0.75 x 0.25 Dimensions

For BEAM (ADAMS/LINES)

$$\tau_{max} = \frac{3V}{2A}$$

$$\tau_{max} = \frac{M c}{I}$$

$$I_y = \frac{1}{12} b h^3$$

$$= \frac{1}{12} (0.25)(0.75)^3$$

$$I_y = 8.79 \times 10^{-3} \text{ in}^4$$

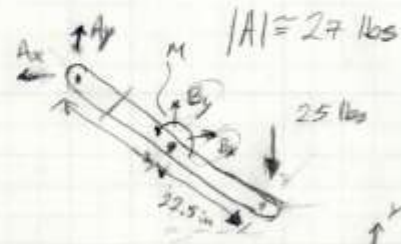
$$M = 144 \text{ lb-in}$$

$$\sigma_x = \frac{(144 \text{ lb-in}) \left(\frac{0.75}{2} \right)}{8.79 \times 10^{-3} \text{ in}^4}$$

$$\sigma_x = 6,143 \text{ psi}$$

$$\tau_{max} = \frac{3(25 \text{ lbs})}{2(0.25)(0.25)}$$

$$\tau_{max} = 200 \text{ lb/in}^2$$



$$|B| = \sqrt{10^2 + 25^2}$$

$$|B| = 27 \text{ lbs}$$

1" x 1"



$$A = 0.25 \text{ in}^2$$

$$I = \frac{1}{12} (0.25)(1)^3 = 0.0208 \text{ in}^4$$

$$\sigma_{max} = \frac{M c}{I} = \frac{(144 \text{ lb-in}) \left(\frac{1}{2} \right)}{0.0208 \text{ in}^4} = 3,462 \text{ psi}$$

$$\tau_{max} = \frac{3(25 \text{ lbs})}{2(1)(0.25)} = 150 \text{ psi}$$

$\frac{3}{8}'' \times \frac{3}{4}''$



$$A = 0.2813 \text{ in}^2 \quad I = 0.0132 \text{ in}^4$$

$$\sigma_{max} = \frac{(-144 \text{ lb} \cdot \text{in}) \left(\frac{0.375}{2} \right)}{0.0132 \text{ in}^4}$$

$$\sigma_{max} = \underline{\underline{-4,100 \text{ psi}}}$$

$$\tau_{max} = \frac{3(25)}{2(0.375)(0.375)}$$

$$\tau_{max} = \underline{\underline{133 \text{ psi}}}$$



$$A = 0.375 \text{ in}^2 \quad I = 0.03125 \text{ in}^4$$

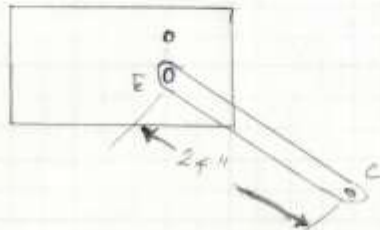
$$\sigma_{max} = \frac{(-144 \text{ lb} \cdot \text{in}) \left(\frac{1}{2} \right)}{0.03125}$$

$$\sigma_{max} = \underline{\underline{-2,304 \text{ psi}}}$$

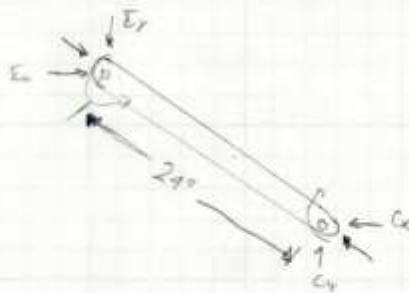
$$\tau_{max} = \frac{3(25)}{2(1)(0.375)}$$

$$\tau_{max} = \underline{\underline{100 \text{ psi}}}$$

- STRESS ANALYSIS FOR SUPPORTING LINK



FBD:



- FROM FORCE ANALYSIS

$$E_x = C_x \quad \& \quad E_y = C_y$$

$$\text{where } C_x = C_y \quad \& \quad E_x = 19.1 \text{ lbs}$$

→ Using $\frac{3}{8}'' \times 1''$ HDPE

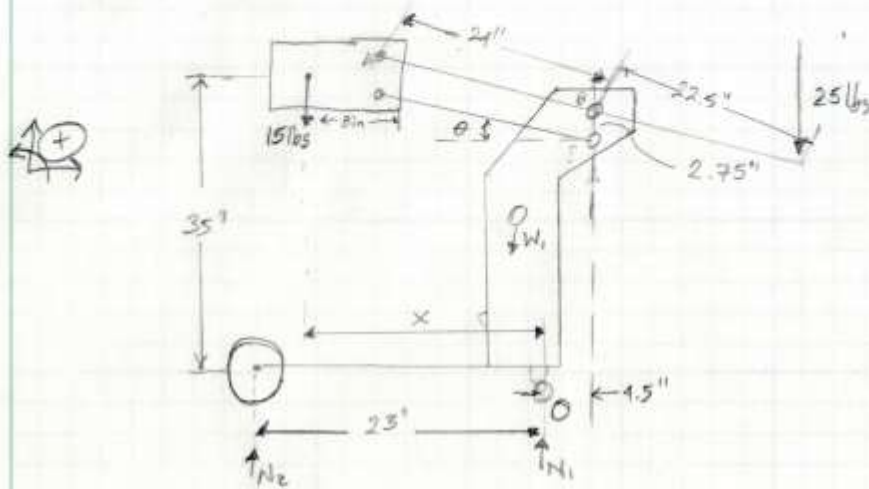
$$\sigma_{\text{comp}} = \frac{F}{A} = \frac{\sqrt{(19.1 \text{ lbs})^2 + (19.1 \text{ lbs})^2}}{(\frac{3}{8} \text{ in} \times 1 \text{ in})}$$

$$\sigma_{\text{comp}} = 72.0 \text{ psi}$$

* NOTE: Member is in compression, max stress comes from axial load.

TIPPING ANALYSIS

$\theta = 45^\circ$ (NOT TO SCALE)



HOPE WEIGHT

Area $\approx 60 \text{ in}^2$ (from Solidworks Model)

$$V = (0.375 \text{ in})(60 \text{ in}^2)$$

$$V = 60 \text{ in}^3$$

$$W_1 = \left(\frac{0.55 \text{ lb}}{\text{in}^3} \right) (60 \text{ in}^3) \left(\frac{1 \text{ lb}}{\text{lb}} \right)$$

$$\underline{W_1 = 2.06 \text{ lb}}$$

$$\underline{\sum F_y = 0}$$

$$N_2 + N_1 = W_1 + 15 \text{ lbs} + 25 \text{ lbs}$$

$$N_2 + N_1 = 42.1 \text{ lbs}$$

$$\underline{\sum M_o = 0}$$

$$- N_2 (23 \text{ in}) + 15 \text{ lbs} (15 \text{ in}) + (2.06 \text{ lb}) (1 \text{ in}) - 25 \text{ lb} (22.5 \cos(45^\circ) + 4.5) = 0$$

$$N_2 \approx -12 \text{ lbs}$$

$$N_1 \approx 54.1 \text{ lbs}$$

$$N_1' = \frac{N_1}{2} = 6 \text{ lbs} \quad (\text{TWO WHEELS})$$

$$N_2' = \frac{N_2}{2} = 27 \text{ lbs}$$

@ TIPPING

$$N_2 = 0$$

$$\sum \tau_0 = 0$$

$$15x + (2.06 \text{ lbs})(1 \text{ in}) - 29 \text{ lbs}(22.5 \cos(45^\circ) + 1.5 \text{ in}) = 0$$

$$15x = 509.16 \text{ in}$$

$$x = \underline{\underline{34 \text{ in}}}$$

→ Mechanism will tip if center of mass of box is $\geq 34 \text{ in}$ from rear wheels.

Appendix J

Safety Hazard Checklist/FMEA

Team: _____Pursuit of Hoppiness_____ Advisor: __Peter Schuster__ Date: _11/9/17__

Y N

- | | | |
|-------------------------------------|-------------------------------------|--|
| <input checked="" type="checkbox"/> | <input type="checkbox"/> | 1. Will the system include hazardous revolving, running, rolling, or mixing actions? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 2. Will the system include hazardous reciprocating, shearing, punching, pressing, squeezing, drawing, or cutting actions? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 3. Will any part of the design undergo high accelerations/decelerations? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 4. Will the system have any large (>5 kg) moving masses or large (>250 N) forces? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 5. Could the system produce a projectile? |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> | 6. Could the system fall (due to gravity), creating injury? |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> | 7. Will a user be exposed to overhanging weights as part of the design? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 8. Will the system have any burrs, sharp edges, shear points, or pinch points? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 9. Will any part of the electrical systems not be grounded? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 10. Will there be any large batteries (over 30 V)? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 11. Will there be any exposed electrical connections in the system (over 40 V)? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 12. Will there be any stored energy in the system such as flywheels, hanging weights or pressurized fluids/gases? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 13. Will there be any explosive or flammable liquids, gases, or small particle fuel as part of the system? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 14. Will the user be required to exert any abnormal effort or experience any abnormal physical posture during the use of the design? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 15. Will there be any materials known to be hazardous to humans involved in either the design or its manufacturing? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 16. Could the system generate high levels (>90 dBA) of noise? |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> | 17. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, or cold/high temperatures, during normal use? |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> | 18. Is it possible for the system to be used in an unsafe manner? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 19. For powered systems, is there an emergency stop button? |
| <input type="checkbox"/> | <input checked="" type="checkbox"/> | 20. Will there be any other potential hazards not listed above? If yes, please explain on reverse. |

For any “Y” responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
The system will include wheels, rollers, and a belt that all roll simultaneously.	The plan is to cover the belt as well as the pinch points on the system.	1/11	3/10
The mechanism could potentially fall from gravity as it will be holding much of the weight at a high center of gravity.	To correct this, with added analysis we can determine if the device will tip over utilizing statics.	1/11	2/15
The mechanism will carry a basket that will be hanging from a certain height. The basket will be holding a great amount of tennis balls.	To correct this, the team can implement stability into the mechanism so that the basket is sturdier from its hanging position	1/11	2/15
The mechanism will be used in an outside environment and could be used during high humidity/fog and cold or hot temperatures.	To correct this, we will make sure that the materials we use are highly resistant to corrosion and the materials are insensitive to temperature changes.	1/25	1/30
It is possible for this to be used unsafely: for example if someone tried to sit on the basket.	We can add a sticker that indicates to only use the device for its intended purpose	1/25	1/30

Table J.1. Design FMEA for Paddlewheel Mechanism

System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurrence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurrence	Criticality
Paddlewheel/ Raise balls	Paddlewheel cannot lift balls into basket	Balls unable to raise	9	1) paddle breaks/bends 2) shaft becomes misaligned 3) paddle loses stiffness	1) use right material for paddles 2) use collars to stabilize 3) make sure edges are rounded	2	Testing	1	18	Research types of materials for paddles, determine position to place paddles on mechanism	George DeGrandis (5/8/2018)	Testing many different types of materials for paddles	7	2	14
Drive/ Mobility (transport)	lots of resistance to pushing	a) becomes harder to push b) wont move	4	1) wheels become misaligned 2) wheels lock in place 3) wheels fall off	1) stress analysis on wheels 2) right fasteners selection 3) fatigue analysis	3	Testing	1	12	Test castor wheels	Alex Morales (2/10/2018)	1) implement castor wheels in back 2) Front wheels similar to push mower	1	3	3
Drive/ Transferring wheel power	Pinion Gear doesn't transfer power	Paddlewheel is unable to lift tennis balls	9	1) rocks in pinion gear 2) gears become misaligned 3) gear teeth wear down	1) stress analysis 2) proper gear selection	3	Testing	1	27	Test final prototype for lifting tennis balls	George DeGrandis (4/15/2018)	Made sure fits are tight and gear interface is protected	5	4	20
Drive/ Easy to use	Wheels or bearings stuck	Mechanism becomes harder to push	6	1) wheels become misaligned 2) wheels lock in place 3) wheels fall off 4) bearings wear out 5) something gets stuck in mechanism	1) shelter wheel shaft/bearings 2) bearing analysis	4	Testing	2	48	Lots of testing in different environments, determine the life of the bearings. Research on weather resistant bearings.	George DeGrandis (1/9/2018)	Bearings research and type of material for different environments	3	3	9
Basket/ Stores tennis balls	Balls bounce out of basket	Cannot hold as many tennis balls	3	1) basket is bent/broken 2) basket is not large enough 3) basket is loose	1) pick a strong enough basket 2) proper fastening	2	Testing	1	6	Find proper dimension for basket	Alex Morales (1/9/2018)	Basket will include lid that will prevent balls from bouncing out	6	2	12
Basket/ Securely transport balls	Lid does not stay closed	Balls come out during transport	2	1) basket gets bent/broken 2) lid doesn't lock into place 3) lid breaks	1) testing on lid 2) locking mechanism	4	Testing	1	8	Research different types of bins/basket and material	Alex Morales (1/9/2018)	Foldable lid that is securely placed on top of basket	6	2	12
Linkages/ Lift Basket	Basket not raised high enough or at all	Have to bend down to reach tennis balls	3	1) linkages not stiff enough 2) fasteners break under weight	1) proper material selection for linkages 2) proper fasteners	2	Testing	1	6	Test to make sure basket is raised high enough	George DeGrandis (5/8/2018)	Deflection test to make sure the basket is raised high enough	2	4	8
Linkages/ Hold Basket Up	Basket falls back down after raising	Balls essentially at ground height	4	1) spring pin gets stuck 2) Holes for spring pin become worn down	1.) research and investment in proper spring pin	2	Testing	1	8	Try different spring pins	Tyler Noxon (5/1/2018)	Spring pin tested in HDPE, works well and shows no signs of wear	3	3	9
General/ Hold everything together	parts are loose	a) device is not stable b) device falls apart c) customer is injured	6	1) belt falls off 2) wheels fall off 3) arms/ basket fall off	1) stress analysis 2) proper material selection 3) redundant fasteners	4	Testing	2	48	Use lock-tight in assembly Use redundant fasteners for safety	Alex Morales (1/9/2018)	Ensure enough fasteners are used	3	3	9
General/ Ease of use	Bearings wear out	device doesn't roll well	4	1) bearings need lubricant 2) bearings are corroded 3) bearings are contaminated	1) bearing analysis and proper bearing selection	5	Testing	3	60	Lots of testing in different environments, determine the life of the bearings. Research on weather resistant bearings.	George DeGrandis (1/9/2018)	Bearings research and type of material for different environments	3	3	9

Appendix K

Design Verification Plan and Results Table (DVP&R)

Senior Project DVP&R													
Date: 6/1/18		Team: Pursuit of Hoppiness		Sponsor: Professor John Chen		Description of System: Tennis Ball Pick-Up Hopper				DVP&R Engineer: Alex Morales, George DeGrandis, Tyler Noxon			
TEST PLAN										TEST REPORT			
Item No	Specification #	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	1	Carry Enough Tennis Balls	Basket needs to carry 65 balls	Tyler	FP	2	C	5/17/2018	5/17/2018	70	2	0	Bin made of HDPE with higher volume. Able to hold 70+ tennis balls.
2	2	Entire mechanism must be under 25 lbs	10-25lbs	George	FP	1	Sys	5/1/2018	5/8/2018		1	0	-
3	3	Transportability	Disassemble under 2 min	Alex	SP/FP	2	Sys	5/1/2018	5/8/2018	4 minutes	0	1	Stopwatch used to collapse mechanism
4	4	Easy-To-Use	30 lb/> force to push	Tyler	FP	15	Sys	5/24/2018	5/24/2018	Max 18.6	15	0	Push/Pull Force gauge used
5	5	Comfortable	Pass/Fail comfortable for use to maneuver/carry	George	SP/FP	2	Sys	5/1/2018	5/8/2018	Pass	2	0	Easy to maneuver around flat surfaces
6	6	Purely Mechanical	Self-powered	Alex	SP	2	Sys	1/5/2018	1/15/2018	Pass	1	-	The mechanism is purely mechanical
7	7	Adjustable	Adjusted to different heights for all users (5%F to 95%M)	Alex	FP	1	C	5/1/2018	5/8/2018	-	-	-	No component added to final working prototype that includes adjusting
8	8	Linkage Deflection Test	3 inches vertically	Alex	FP	1	C	5/1/2018	5/8/2018	0.5 in	1	0	Equipment: Tape Measure
9	9	Tipping Analysis	No tipping	Alex	SP/FP	1	Sys	5/1/2018	5/8/2018	Pass	1	0	No tipping while in motion or stand-still
10	10	Weather Test	Functions through weather conditions	George	FP	1	Sys	5/1/2018	5/8/2018	-	-	-	Made of HDPE and aluminum
11	11	Safety Test	Pinch points are unreachable	George	FP	1	Sys	5/1/2018	5/8/2018	-	-	-	-

Figure K.1. Final DVP&R Table.

Appendix L

Operators' Manual

Paddlewheel Mechanism

This user's manual includes instructions for product use and safety information. Read this section entirely including all safety warnings and cautions before using the product.

Important: This mechanism is meant for use on a tennis court by tennis players of all ages. Before using this product, the user should be familiar with the operation and safety risks.

<p><u>Warning:</u> Do not use product while other players are engaged in a match.</p>
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The following instructions include everything you need to know to collapse the Paddlewheel Mechanism for ease of transportability.



Collapsing the Paddlewheel

Tools Required: Two (7/16)" wrenches

Follow these directions to collapse the Paddlewheel Mechanism.

- 1) Unlock the two spring-loaded pins from both sides of the mechanism and raise the bin up until it locks into the second hole or is parallel to the ground
 - a. **Note:** Currently, the product needs the assistance of two individuals to unlock the pins and raise the bin. The plan for future advancement, is to have one locking pin that is enabled through a cable pull system.



- 2) Remove nuts and bolts from upper handle to collapse and move the ramp toward and over the paddles.
 - a. **Note:** Two bolts and nuts on both sides connect the handles and upper linkages. The upper two bolts and nuts are to be removed in this step.



- 3) Loosen bolts from the front side pieces to move the front subassembly inward.



Caution: As the user is lowering the bin, make sure there is no one under the bin as this could lead to injury.

- 4) Unlock the spring-loaded pins from both side of the mechanism and lower the bin up onto the ramp.



Tips for Operation

Caution: The user should be familiar with all safety concerns of using the Paddlewheel Mechanism. The Paddlewheel Mechanism has pinch points around the paddles that can injure the user or a non-user if a hand is near the paddles while in motion. Misuse of the Paddlewheel Mechanism could injure people or damage the product.

To use the Paddlewheel Mechanism, simply maneuver the mechanism around the tennis court to collect tennis balls. Move the Paddlewheel Mechanism over the tennis balls to collect them.

The user should be aware of the functions of the Paddlewheel Mechanism when in use. Currently, the mechanism picks up tennis balls effectively. At times, a tennis ball or two will jam. To move around this problem, simply move backwards and attempt to collect the tennis ball again. A recommended walking speed of 3 ft/s will maximize the efficiency of the product.

When the bin is full, the user will disengage the spring-loaded pins and push down on the handles to lift the bin up to the desired height. It is important to note that at this stage of building the working prototype, the lifting of the basket requires a minimum of two individuals.

Caution: As the user pushes down on the handle to lift the bin, the Paddlewheel mechanism tends to lift from the front of the prototype. It is advised to do this procedure with two individuals as the tipping of the mechanism can cause injury to the user or players nearby.

Maintenance

No active maintenance is required to keep the Paddlewheel working efficiently. The Paddlewheel mechanism is water resistant and is used outdoors but should not be left outside standing in water or sitting in the sun. It should also not be exposed to extreme heat.

Appendix M

Gantt Charts

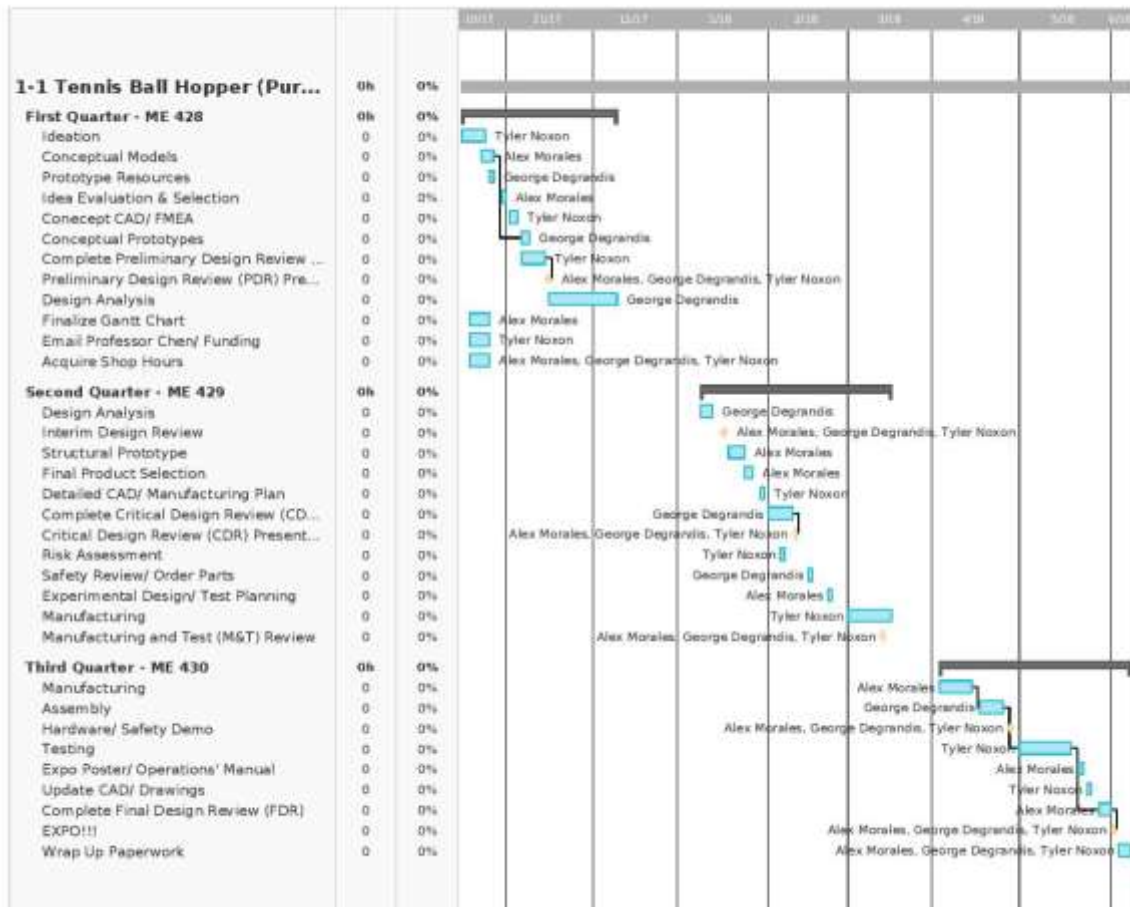


Figure M.1. Initial Gantt chart created with TeamGantt.

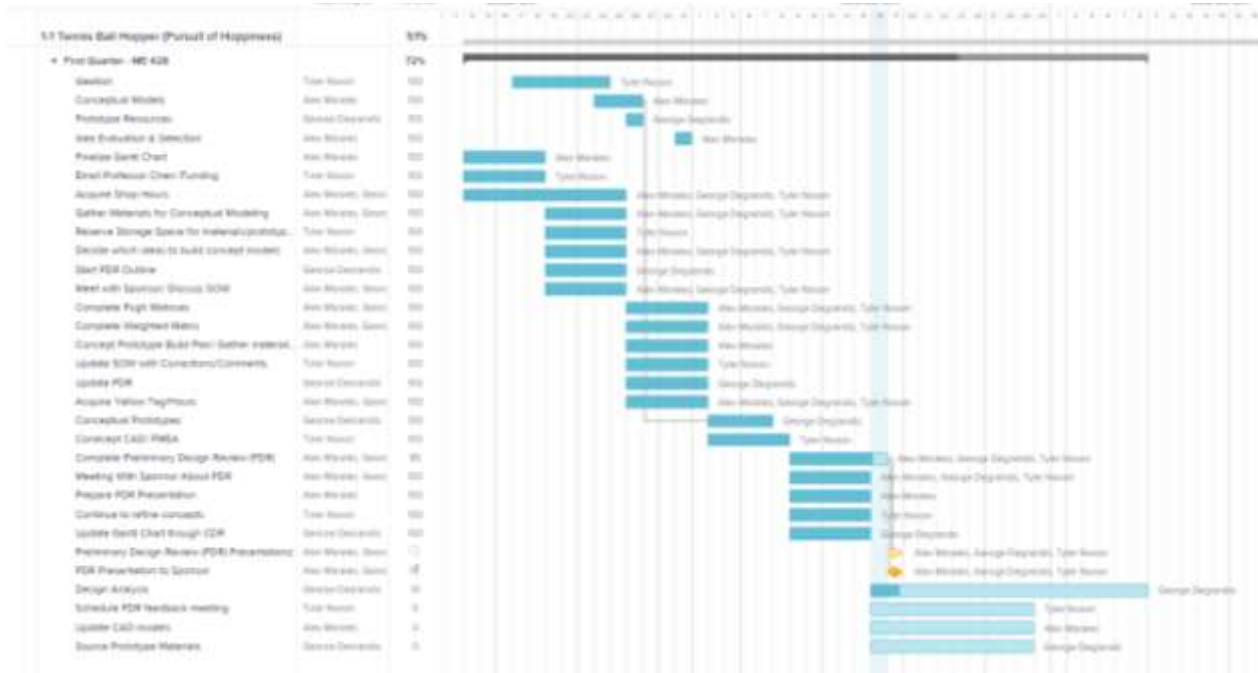


Figure M.2. Updated Gantt chart with weekly tasks through first quarter.

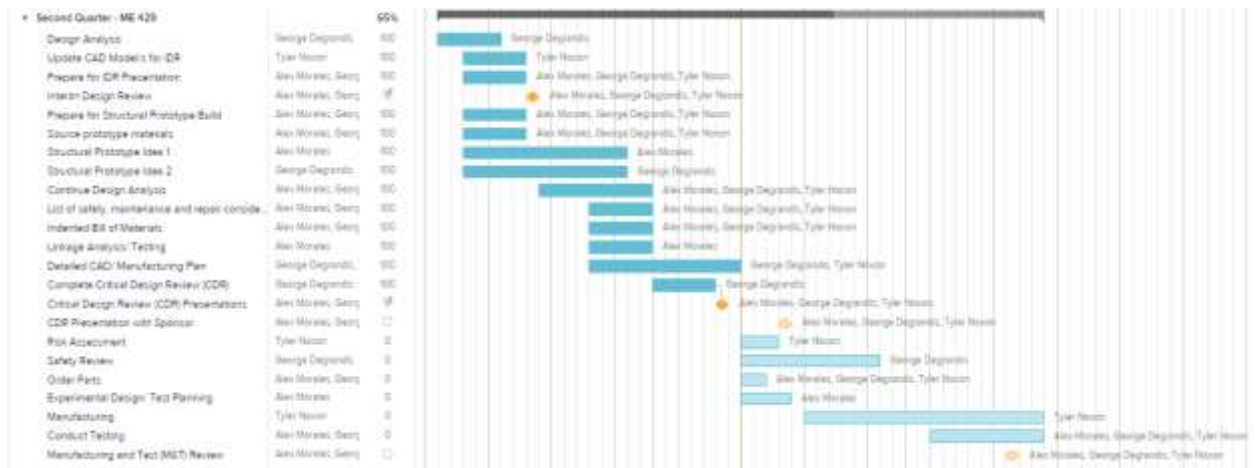


Figure M.3. Updated Gantt chart for second quarter with weekly tasks through CDR.

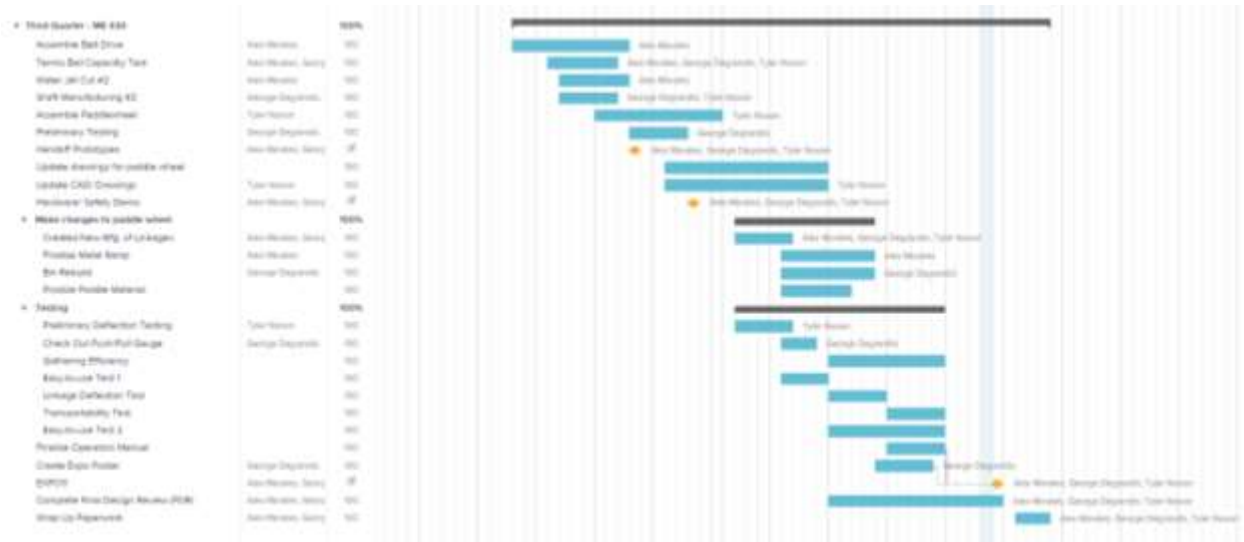


Figure M.5. Updated Gantt Chart for Third Quarter Through Final Design Review .